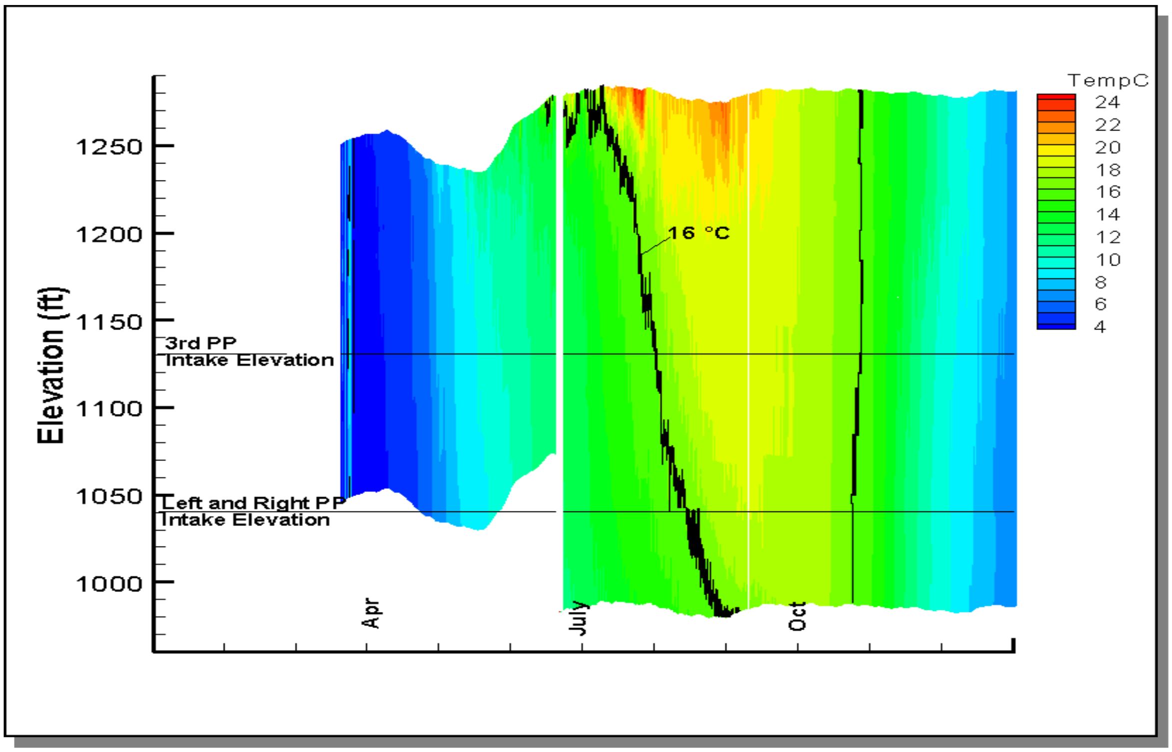
Grand Coulee Dam — Lake Roosevelt

Initial Review of Three Strategies to Manage Water Temperature at Grand Coulee Dam

Discussion Paper — DRAFT



U. S. Department of the Interior
Bureau of Reclamation

June 12, 2003

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INITIAL REVIEW OF THREE STRATEGIES TO MANAGE WATER TEMPERATURE AT GRAND COULEE DAM

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U. S. Department of the Interior
Bureau of Reclamation

Technical Service Center
Prepared for:
Grand Coulee Power Office
Pacific Northwest Region Office

June 12, 2003

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Summary —

Initial Review of Three Strategies to Manage Water Temperature at Grand Coulee Dam DRAFT — June 12, 2003

In September 2002, a preliminary draft Total Maximum Daily Load (TMDL) was produced to address issues concerning water temperatures in the Columbia and Snake Rivers. Shortly after, a revised draft TMDL was prepared in November 2002 and a Summary Implementation Strategy (SIS) was drafted early in 2003 (in progress). The temperature TMDL scope includes 15 major hydropower dams on the mainstem Columbia River and lower Snake River. Grand Coulee Dam is identified as a major component in the draft TMDL and SIS documents because of the large capacity of the facilities and conditions applied in the TMDL plan development.

Recent discussions concerning the Columbia River temperature TMDL, have raised a number of questions concerning *attainability*; including physical limitations and economic consequences of using structural or operational modifications at Grand Coulee to contribute toward the proposed TMDL temperature criteria. Long-term steps cited in the draft SIS include investigation of three operational or structural strategies to improve release water temperatures at Grand Coulee. This review was undertaken by Reclamation to obtain advance information regarding potential costs and temperature improvement benefits associated with these three options. To accomplish this initial review, certain assumptions were applied and more detailed study is necessary to confirm the review findings and evaluate inter-related hydrodynamic processes.

Any structural or operational modifications considered at Grand Coulee Dam to modify water temperatures downstream in the Columbia River would have practical engineering and economic constraints. Grand Coulee is the single largest hydroelectric facility in North America, with three separate powerplants, 24 generation units, and a capacity that exceeds the average annual peak flow of over 200,000 cubic feet per second (cfs). The total generation capacity is nearly 6500 megawatts and Grand Coulee is an essential component in meeting the peak power demands for the entire western area power grid. Modifications at Grand Coulee are inherently costly because of the complicated configuration and massive scale of these existing facilities.

The feasibility of producing and maintaining significant temperature improvement downstream is uncertain because of the inherent watershed conditions and limitations of existing facilities that were designed for specific purposes. Operations are governed primarily by the irrigation water supply, power generation, and flood control objectives of the project. Operating flexibility must accommodate the Columbia Basin hydrologic fluctuations while attempting to optimize efficient use of water resources. Structural modifications will also require changes in operations to alter release temperatures. In addition, the existing recreation, in-lake fisheries, and other resources

associated with Lake Roosevelt may be impacted by changes to the dam facilities or operating characteristics. All these factors must be considered collectively to gain perspective on strategies that might produce temperature benefits for downstream fisheries in balance with the extensive water resource systems and operating criteria already in place.

Major cost factors and potential benefits associated with three optional temperature management strategies considered in this review are summarized in table S-1. Cost estimates were derived from a basic layout of structural features and experience drawn from similar projects. Potential temperature management benefits were based on projected water volumes, stratification duration, average daily temperatures and flows, and simplified steady-state analysis.

Table S-1. Summary of initial review including projected range of costs and potential benefits of strategies to improve late-summer temperature conditions downstream of Grand Coulee Dam.

Strategy	Initial estimated costs and factors	Potential temperature benefit and factors
Optional Strategy 1 Modified operation of the Left, Right, and 3rd Powerplants to alter release water temperatures.	Low costs are expected to shift power load between powerplants if peaking operations and total generation rates are comparable to existing conditions. ● specific details of operational changes are required to estimate actual costs ● Long term O&M costs of shifting power loads requires more detailed study	Maximum potential to reduce number of days exceeding 16 ºC from 87 to 63 days based on daily averages, assumed water volumes, and stratification for 2001 data. ● potential reduction could be less if hourly operations criteria are considered ● benefits based on review assumptions, neglecting dynamic conditions
Optional Strategy 2 Construct multi-level intake structures at the Left and Right Powerplants to allow withdrawal of water at selected depths.	Pre-appraisal estimated cost including 25% contingency: $ 270,000,000 for Left Powerplant; $ 250,000,000 for Right Powerplant. ● costs reflect large scale of facilities and total of 18 penstock intakes ● could consider modifying only one of the powerplants (the Left Powerplant) ● might also consider reducing height of intake structures to reduce costs	Greater efficiency is expected to extend temperature benefits by 3 to 4 days over estimates for Optional Strategy 1. ● multi-level intakes can access deeper, colder water volume, and also evacuate warmer water from upper layers ● efficient thermal regulation is expected, but cannot quantify without hydrodynamic modeling to evaluate how operations may alter stratification and mixing patterns
Optional Strategy 3 Structural and/or operational changes to the Banks Lake Pump-Generation Plant facilities.	Pre-appraisal estimated cost including 25% contingency: $ 84,000,000 for all 12 pumping and pump-generator units. ● relatively high cost for uncertain benefit ● could consider modifying only six pump units and/or reduce structure height for only surface water takeoff	Only incremental benefit expected for this option based on review assumptions. ● could combine with other strategies to improve warm water removal (if needed) ● effects limited to small volume of water in proportion to total river flows ● need 3-d modeling of the forebay area to fully test and confirm effectiveness

Note: Results are based on assumptions and information available for this initial review. Projected costs and benefits assume existing hydropower, flood control, water storage, and maintenance requirements are accommodated by each optional strategy considered. This review focused on strategies to manage temperatures in the downstream river. More detailed investigation is necessary to evaluate reservoir water temperatures, hydrodynamic effects, or impacts on in-lake fisheries. All results should be verified and refined as appropriate before proceeding with any corresponding actions.

The three temperature management strategies considered in this review all depend on the summer thermal stratification conditions in the reservoir, conditions in the upper watershed, and the fixed constraints imposed by functional attributes of the existing dam facilities. The overall approach involves using the different intake elevations of the existing left, right, and third powerplants, or constructing multi-level intake structures at Grand Coulee to withdraw deeper, colder water from the reservoir to lower release water temperatures during late-summer months. In early summer, removing some warmer surface water may also help to reduce heat transfer and conserve more of the colder water for release later, when river temperatures exceed TMDL objectives.

Additional Information Needs

It is important to note that many processes that influence reservoir hydraulic transport and water temperature characteristics are dynamic in nature. For example, hydrodynamic properties, heat transfer, thermal density gradients, mixing patterns, interflows, and effective flow-through rates are interrelated. The hydraulic flux at Lake Roosevelt is impressive given that the reservoir is about 160 miles long and contains over 9 million acre-feet of water, and yet the average retention time is only about 45 days. Even under these conditions, the reservoir experiences some thermal stratification from July through September (see temperature profile plots in appendices).

This review was based on the data collected under existing conditions. Consequently, the results reflect the underlying assumptions, and do not indicate how temperature conditions may actually respond to changes in the dam facilities or reservoir operations. For example, evacuating warm surface water may increase the volume of cooler water by reducing vertical heat transfer, or alter stratification stability or interflow effects. This cannot be accurately predicted from existing data although either case could have implications for effective temperature management. Additional information could help to evaluate the collective effects of different conditions or strategies.

- Hydrodynamic Simulation Modeling – A two dimensional (2-d) hydrodynamic reservoir model could be developed to evaluate existing reservoir temperature characteristics or the implications of different management options. This type of model capability is essential to evaluate the effects of structural or operational changes that are not represented by data collected under historic conditions. A fully calibrated 2-d model can provide mechanistic simulation of temperatures and the hydrodynamic density currents or mixing properties that are predicted under modified conditions. For example, simulating these interactions might help to evaluate potential effects of alternative temperature management strategies on Lake Roosevelt water temperatures, in-lake fisheries, or other resources.

- In-situ Temperature Monitoring – Actual release temperatures associated with operations at the existing Grand Coulee powerplants could be examined by installing thermistors on each of the intakes, and recording data under different operating scenarios. The resulting data would help in evaluating the effects of short-term fluctuations and the duration that selected temperature conditions are effectively sustained.

Initial Review of Three Strategies to Manage Water Temperature at Grand Coulee Dam DRAFT — June 12, 2003

1.0 Introduction

The first preliminary draft Total Maximum Daily Load (TMDL) was completed September 2002 to address water temperatures associated with 11 major dams on the Columbia River mainstem to the Canadian border and 4 dams on the lower Snake River (EPA, 2002a). In November, the second draft *Columbia/Snake River Mainstem Temperature TMDL* was issued (EPA, 2002b) and a draft Summary Implementation Strategy (SIS) followed early in 2003 (WADOE, 2003). Other references concerning Columbia River fishery issues and ongoing TMDL planning are available in the latest drafts in progress and related sources on the Internet.

The Bureau of Reclamation (Reclamation) has participated in the TMDL discussions as the operator of Grand Coulee Dam and Lake Roosevelt—the largest hydropower production and water storage project on the Columbia River system.

Recent discussions concerning the Columbia River temperature TMDL, have raised a number of questions concerning *attainability*; including physical limitations and economic consequences of using structural or operational modifications at Grand Coulee to contribute toward the proposed TMDL temperature criteria. Long-term steps cited in the draft SIS include investigation of three operational and structural strategies to alter release water temperatures at Grand Coulee. This review was undertaken by Reclamation to obtain advance information regarding potential costs and temperature improvement benefits associated with these three strategies.

What is in this Discussion Paper

This paper summarizes some of the prominent considerations, cost factors, and potential benefits associated with three strategies for managing Grand Coulee release temperatures. This review is based on existing data and information and assumes conditions that maintain current hydropower and reservoir storage functions. Estimated costs and potential temperature management benefits include contingency factors to reflect uncertainties for this preliminary level of analysis. Results are intended to contribute information pertaining to the Columbia River temperature issues that is useful primarily for discussion purposes. More detailed investigations are necessary to evaluate specific actions and refine estimates to reflect the full economic costs and benefits.

The first section is an Introduction to the review scope and approach. This is followed by two sections summarizing the Columbia River TMDL Planning and Water Temperature Standards, and Background on Temperature Management Concepts and Strategies that indicate temperature management opportunities and limitations. The next three sections describe review results for Optional Strategy 1, Strategy 2, and Strategy 3, including the initial cost estimates and potential temperature benefits. In the last section, Future Planning Considerations are discussed. A list of References follows and Appendix A, Appendix B, Appendix C, and Appendix D include relevant supporting information for the review topics addressed.

Topics in this discussion paper are written in a summary outline form. This is intended to help organize information and illustrate different aspects of the TMDL planning and temperature issues specifically related to Grand Coulee Dam. Supporting technical information, graphics, and data plots are provided in the attached appendices. This review was completed by staff members from the Reclamation Technical Service Center; Structural and Architectural Group; Water Resources Research Laboratory; Estimating, Specifications, and Value Program Group; and the Land Suitability and Water Quality Group, with review and coordination provided by Reclamations' Pacific Northwest Region and Grand Coulee Power Office.

Review Scope and Approach

The overall purpose of this review is to compile information that indicates the relative magnitude of costs and ability to manage water temperatures downstream of Grand Coulee to work toward meeting the TMDL objectives. Existing conditions at Grand Coulee Dam, Lake Roosevelt, and downstream in the Columbia River were considered to evaluate major cost factors and potential temperature management effects for three alternative strategies:

- **Optional Strategy 1** - Modify operations at the existing left, right, and third powerplants to regulate water temperatures released at Grand Coulee Dam.
- **Optional Strategy 2** - Install multi-level intake structures at left and right powerplants to allow selective withdrawal of colder or warmer water from the reservoir.
- **Optional Strategy 3** - Implement structural and/or operational changes at the Banks Lake pumping facilities to alter temperatures in the Grand Coulee Dam intake forebay.

All three strategies rely on thermal stratification in the reservoir. The approach centers around the ability to alter release water temperatures by taking advantage of the seasonal stratification patterns. Each strategy considered involves modifying Grand Coulee Dam operating procedures or structural components as a means to:

- Evacuate warmer water in upper reservoir layers in the early summer,
- Conserve more of the colder water volume in deep layers of the reservoir,
- Tap into the colder water as release temperatures start to exceed the criteria,
- Adjust thermal stratification, flow through, or seasonal timing patterns.

Each of the optional strategies addresses aspects of this overall approach and the three strategies represent a continuum or range of measures to consider. For example, the first strategy involves modifying hydropower operations by taking advantage of the different intake elevations of the three existing Grand Coulee powerplants, to allow selective use of colder or warmer water layers without structural changes. The second option increases the selective withdrawal efficiency at the cost of building huge multi-level intake structures for the left and right powerplants (intake modifications at the third powerplant were deemed impractical). In effect, the third strategy is a means to enhance the withdrawal of warm upper water layers that could be done in conjunction with the other two options. All three mechanisms could produce significant changes in reservoir hydrodynamic properties including internal currents, interflow characteristics, or the strength or duration of temperature gradients and longitudinal stratification patterns.

The review approach is also based on the current water temperature standards as summarized in the draft TMDL (EPA, 2002b). The proposed TMDL allocations are based on a “site potential” definition of what temperatures would be theoretically in an un-impounded condition, accepting existing conditions in the upstream watershed. TMDL site potential criteria are not available at this time, and consequently, a maximum temperature criteria of 16 °C was used in this review based on current Washington state standards for river reaches extending from the International Boundary to Grand Coulee Dam and from Grand Coulee to Chief Joseph Dam.

Assumptions and Other Considerations

Certain assumptions and information needs were identified to define the review approach and compensate for uncertainties in the initial evaluations. Other assumptions and considerations are described later in the discussion sections for each optional strategy.

- Reservoir stratification conditions used to evaluate temperature effects are based on the critical periods August 1st to October 31st, and November 1st to February 5th.
- The 16 °C maximum daily temperature criterion was used as a reference for this review until target allocations, site potential, and other TMDL issues are resolved.
- Structural cost estimates are considered sub-appraisal level and are based only on basic layout of major features and experience from similar Reclamation projects.
- Operational cost estimates involved qualitative assessment of the implications of shifting power operations between powerplant facilities based on average daily flow rates.
- Potential temperature benefits are based on a simple steady-state analysis using projected reservoir water volumes, stratification duration, and average daily flow rates.
- Data were reviewed for year 2000 as a typical runoff year, 1998 as a year with average runoff and hot climate conditions, and for other water years when possible.
- Projected costs and benefits assume the existing power, flood control, water storage, and maintenance requirements are accommodated by each strategy considered.
- This discussion paper is based on limited review, and the information should not be taken out of context or without consideration of the factors described. More detailed analysis is recommended to confirm any specific issues or results suggested in this paper.

2.0 Columbia River TMDL Planning and Water Temperature Criteria

The Columbia/Snake Rivers Temperature TMDL planning is still in progress and some criteria could change. Information regarding the ongoing Columbia River TMDL process is available from various sources (EPA et al, 2001). This review focused on the water quality (temperature) criteria and concepts described in the current draft TMDL planning documents. The draft criteria and premises are likely to undergo additional review and adjustment as the planning progresses; however, the following information indicates the current status and provides a point of reference to consider the potential implications of temperature management alternatives.

Temperature TMDL Factors Concerning Grand Coulee Dam and Lake Roosevelt

The following references provide general background into the ongoing TMDL process and more specific information concerning target temperature allocation methods, management implications for Grand Coulee and Lake Roosevelt, and the strategies explored in this review:

Primary references for Columbia River temperature TMDL issues—

- *Columbia/Snake Rivers Temperature TMDL* - Preliminary Draft. September 13, 2002. U.S. Environmental Protection Agency. Washington D.C. (EPA, 2002a).

The first draft provided a general introduction to the Columbia River TMDL and background for applying state water quality standards as a basis to develop the TMDL temperature targets and allocations. In particular, it describes the use of "site potential" as a modified representation of natural pre-dam conditions, and includes a discussion of the implications of using daily cross sectional average temperatures in the one-dimensional (1-d) heat budget model developed and used by EPA to establish the draft TMDL numeric criteria.

- *Columbia/Snake Rivers Temperature TMDL* - Draft. November 13, 2002. U.S. Environmental Protection Agency. Washington D.C. (EPA, 2002b).

The second draft (not released for open review) describes the TMDL approach, draft criteria, and gross allocations. The draft also acknowledges Reclamation participation on issues concerning Grand Coulee Dam and the Columbia Basin Irrigation Project and identifies the need to evaluate potential temperature improvement measures:

> *"…to determine if they are feasible and will have a beneficial effect on water temperature downstream of Grand Coulee while not causing impairment of temperature upstream of the dam in Lake Roosevelt."*

This second draft also includes a well-written summary that describes the TMDL process, purpose, and objectives, including the following description of three main goals and overall approach of the ongoing TMDL planning process:

> *"Implementation planning to improve water temperature could be very costly, especially for the federal and public utility district dams on the rivers. Therefore, it is prudent to verify that a problem exists and to quantify the extent of the problem before investing a great deal. Essentially, the role of the TMDL in improving temperature in the Columbia/Snake River mainstems is to clarify these issues. The purpose of the TMDL is to:*
>
> 1. *define temperature targets;*
> 2. *quantify the temperature problem on the mainstem;*
> 3. *determine the level of improvement needed.*
>
> *The TMDL, therefore, uses water quality modeling to determine the specific water temperature targets for the mainstems on the basis of state water quality standards. The water quality standards require identification of what the temperatures would be in the absence of human activities on the mainstems."*

- *Summary Implementation Strategy* - Preliminary Draft (Columbia/Snake River Temperature TMDL). February 25, 2003 (revised in May 2003). Washington Department of Ecology. Spokane, Washington. (WADOE, 2003).

This first draft implementation strategy for the TMDL cites specific short and long term actions to work toward the draft TMDL goals. The three temperature management options assessed in this review are cited as long term investigation needs, although this review is only intended to gain insight into factors that could influence the viability of these options and does not replace the more detailed long term investigations indicated. The SIS also includes a discussion of the "Reasonable Assurance" issues that acknowledges physical and economic attributes of existing large-scale dams and the need for comprehensive assessment of the total costs and the relative significance of benefits associated with potential improvement actions.

Other important references of interest include—

- *Problem Assessment for the Columbia/Snake River Temperature TMDL* - Preliminary Draft. November 4, 2002. Environmental Protection Agency. Washington D.C. (EPA, 2002c).

In addition to describing fishery issues associated with thermal heating in reservoirs, this report also cites other temperature related factors that could impact fish population survival including global warming, loss of alluvial cool water refuge zones, and fish ladders with water that is too warm. This problem assessment document was recently updated in February 2003.

- *Final Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program*. July 28, 1998. Environmental Protection Agency. Washington D.C. (EPA, 1998).

A background reference to *reasonable assurance*, *existence*, and water quality *standards* issues, concerning large dams and other "extremely difficult, historic conditions." Discussion of these issues is continuing at this time, and some criteria may change as TMDL policies are reviewed and these important issues are clarified and resolved through this process.

- *Assessing the TMDL Approach to Water Quality Management*. National Research Council. National Academy Press. Washington D.C. (NRC, 2001).

This report discusses the scientific basis of the TMDL process as a means to accomplish goals of the Clean Water Act. Specific issues include defining designated uses and standards, data quality and monitoring needs, a two-tiered approach for listing impaired waters, water quality modeling and uncertainty analysis methods, and adaptive implementation of TMDL plans.

Projects in scope of draft Columbia/Snake River Temperature TMDL—

Locations by river mile, start of operations, total generating capacity and total storage capacity for each of the 15 dams included in the draft TDML are shown in table 2-1. Projects operated under the Federal Columbia River Power System (FCRPS) and the year that each project began active operations are also indicated in the table.

Table 2-1. Major dams included in the Columbia/Snake Rivers Temperature TMDL (EPA, 2002b).

Project	River Mile Location	FCRPS Projects	Start of Operation	Power capacity (megawatts)	Storage capacity (acre-feet x1000)
Columbia River Mainstem Projects:					
Grand Coulee	596.6	FCRPS	1942	6494	8290
Chief Joseph	545.1	FCRPS	1961	2069	588
Wells	515.8	Non-federal	1967	744	281
Rocky Reach	473.7	Non-federal	1961	1347	440
Rock Island	453.4	Non-federal	1933	622	132
Wanapum	415.8	Non-federal	1963	1038	710
Priest Rapids	397.1	Non-federal	1961	907	321
McNary	292.0	FCRPS	1957	980	1295
John Day	215.6	FCRPS	1971	2160	2294
The Dalles	191.5	FCRPS	1960	1780	311
Bonneville	146.1	FCRPS	1938	1050	761
Lower Snake River Projects:					
Lower Granite	107.5	FCRPS	1975	810	474
Little Goose	70.3	FCRPS	1970	810	541
Lower Monumental	41.6	FCRPS	1969	810	351
Ice Harbor	9.7	FCRPS	1962	603	400

Note: Hydropower operations for projects included in the Federal Columbia River Power System (FCRPS) are coordinated to meet the continuous demands of the western area power grid with greater overall efficiency.

Grand Coulee has the greatest storage and generation capacity of these projects. Reservoir stage and water volume are prominent factors applied in the 1-dimensional (1-d) heat budget model (Yearsley et al, 2001) used to assign temperature impacts for the 15 respective Columbia River dams cited in the current draft TMDL. The draft TMDL indicates that impacts of Grand Coulee Dam (Lake Roosevelt) could be as high as 6.23 ˚C in late fall, based on the 1-d model analysis with existing conditions upstream and no effects attributed to Spokane River inflows.

Site potential basis for defining TMDL target temperature allocations—

The draft TMDL (EPA, 2002b) indicates it is reasonable to apply the most stringent standards for each river reach because it is an interstate TMDL and because this is the only way to ensure that all temperature standards are met for the affected segments. From there, the current draft TMDL proceeds to a discussion of how target temperatures were derived for the Columbia River based on mathematical modeling and assumptions concerning "*natural temperature*" and the concept of "*site potential*" which does not account for possible impacts from altered water temperatures and flow regimes outside the TMDL project area.

> *"Natural temperature is considered to be the water temperature that would exist in the river in the absence of any human-caused pollution or alternations. This definition applies to all human activities: those that effect the river temperature directly such as point sources of warm water or dams and impoundments; and that effect river temperature indirectly such as development in the watershed and air pollution that results in climate change."*

The draft TMDL acknowledges that there are few temperature data available for the free-flowing river that would reflect the natural temperatures prior to the advent of human sources of thermal energy in the watershed. As a result, a 1-d energy heat budget model was developed to simulate Columbia River temperature conditions (Yearsley et al, 2001). Brief technical discussions are also included to describe the implications of using daily cross-sectional average temperatures in the 1-d model simulations and the determination of site potential temperatures.

> *"Development of the target temperatures for the TMDL depends on an understanding of natural temperature. A mathematical water quality model was used to simulate temperature conditions in the mainstems of the Columbia and Snake rivers in the absence of human activity in the mainstems. The simulation utilizes existing flow and temperature in the tributaries and at the TMDL boundaries. These simulated temperatures are an approximation of natural conditions because they do not account for possible impacts from altered water temperature and flow regimes outside the TMDL project area. To maintain the distinction from purely natural temperatures, these simulated temperatures are referred to as site potential temperatures. This TMDL is based on the site potential temperatures; the temperatures that are estimated to occur in the absence of human activity in the mainstems."*

Presumably, this means that modified conditions in upstream waters are considered as a baseline condition for that reach. It appears that the cross-sectional averaged site potential temperatures derived from 1-d model simulations were used to set the target gross temperature allocations in the draft TMDL, but the actual site potential values derived for reaches near Grand Coulee Dam are not provided in the current draft plan. As a result, the 16 ˚C daily maximum temperature criteria was used as a point of reference in this initial review. This reference temperature issue is complicated and may warrant more attention as the TMDL planning progresses.

Temperature Criteria Relevant to Grand Coulee and the Upper Columbia River

The draft temperature TMDL (EPA, 2002a) indicates the most stringent water quality standards are used in setting target goals and allocations to ensure that all criteria are met. In this case, the Oregon standards are the most stringent as indicated in table 2-2. These standards were used to set the seasonal TMDL temperature allocation objectives indicated in table 2-3, and the resulting gross temperature allocations cited in the draft TMDL are summarized in table 2-4.

Table 2-2. Water temperature standards for Columbia River reaches near Grand Coulee Dam.

Columbia River Reach	Criterion	Natural Temp < Criterion	Natural Temp > Criterion
International Boundary to Grand Coulee Dam	16 ºC Daily Maximum	Natural + 23 / (T+5)	Natural + 0.3
Grand Coulee to Chief Joseph Dam	16 ºC Daily Maximum	Natural + 23 / (T+5)	Natural + 0.3
Oregon Border to Columbia River mouth	12.8 / 20 ºC Daily Maximum (seasonal)	Natural + 1.1 ºC	Natural + 0.14 ºC

T = the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.
Reference: Summary, Page xi; draft Columbia/Snake Rivers Temperature TMDL (EPA, 2002b).

Table 2-3. Summary of seasonal Columbia River TMDL temperature allocation objectives.

Period	TMDL temperature allocation objectives
February 6th to July 31st	No allocations required
August 1st to October 31st	Allocation to achieve site potential temperature + 0.14 ºC
November 1st to February 5th	Allocation to achieve site potential temperature + 1.1 ºC

Reference: Summary, Page xiv; draft Columbia/Snake Rivers Temperature TMDL (EPA, 2002b).

Table 2-4. Columbia River Temperature TMDL summary of gross allocations for Grand Coulee reach.

Columbia River Reach	Temperature increase allowed August 1st to October 31st	Temperature increase allowed November 1st to February 5th
International Border to Grand Coulee	.0009 ˚ C	.1209 ˚ C
Grand Coulee to Chief Joseph Dam	.0009 ˚ C	.1209 ˚ C

Reference: Summary, Page xvi; draft Columbia/Snake Rivers Temperature TMDL (EPA, 2002b).

3.0 Background Information on Temperature Management Concepts and Strategies

Grand Coulee Dam was identified as the largest component in the current draft TMDL based on results of the heat budget model developed for the Columbia River system. Grand Coulee does have the greatest water storage volume and hydrogeneration capacity of the 15 dams included in the temperature TMDL (table 2-1); however, there are many factors that can influence the ability to modify conditions to achieve downstream temperature improvements. Grand Coulee Dam is a massive structure built with over 12 million cubic yards of concrete. The facilities include four separate powerplants (including Banks Lake pump-generation plant) with a compound hydraulic configuration (figure 3-1) and complicated operational characteristics.

Figure 3-1. Aerial photograph of Grand Coulee Dam showing the configuration (facing downstream), of the Right Powerplant, center spillway, Left Powerplant and the Third Powerplant (angled to original dam structure). Banks Lake pump generation plant and feeder canal are visible in the upper right corner.

The physical and economic feasibility of achieving significant temperature regulation is subject to the inherent watershed conditions and limitations of existing facilities that were designed for specific water resource functions. Dam operations are governed primarily by the irrigation water supply, hydropower, and flood control functions originally authorized for the project.

Conditions in the reservoir and downstream waters are subject to hydrologic fluctuations that can range widely and the flexibility in operational adjustment has to accommodate these inherent variations while attempting to efficiently optimize the use of water resources. Structural features such as multi-level intakes, where technically feasible, are often costly, and any major structural modifications will further influence operating conditions within certain limitations. In addition, changes in the reservoir release characteristics can produce fundamental changes or more subtle fluctuations in reservoir limnology that cause short-term or longer impacts on in-lake fisheries or other resources that depend on conditions within Lake Roosevelt.

The ability to effectively sustain temperature regulation during critical periods and the actual extent that temperature changes could persist downstream and improve fishery conditions in the Columbia River is not well established and may warrant further investigation. Other factors that can influence river water temperatures and fish survival are cited in the TMDL and supporting references. All these considerations depend on physical and economic constraints that influence their practical feasibility. Ultimately, these investigations should attempt to prioritize actions to avoid expending resources on measures that produce only marginal benefit.

The three temperature management strategies considered in this review all depend on the thermal stratification patterns that occur each summer in the reservoir, conditions in the upper watershed, and constraints associated with dam and reservoir operations. The following paragraphs describe factors that affect all temperature management strategies at Grand Coulee. Each topic represents one aspect or a snapshot at one point in time. However, when considered collectively the pieces can help give some perspective into the current conditions, potential opportunities, and effective constraints on any alternative temperature management strategies.

Existing Structural and Operational Factors that Impact Release Water Temperatures

The intake elevations for the left, right, and third powerplants (table 3-1) will influence the ability to tap into depth zones with warmer or colder temperatures during periods of thermal stratification. The other data in the table illustrates the complicated hydraulic configuration at Grand Coulee because of the three separate powerplants that have multiple generator units and different intake elevations and hydraulic capacities. Conditions are further complicated by the central spillway configuration and the Banks Lake pump-generation facilities located on the left dam abutment. The hydraulic capacities give an indication of the overall potential to use each powerhouse to modify temperatures, with or without structural modifications.

Grand Coulee Dam hydraulic configuration—

Table 3-1. Hydraulic configuration of major components at Grand Coulee Dam.

Component	Number of units	Size of intakes (feet)	Total capacity (ft^3 /s) (1)	Centerline elevation (feet above MSL)(2)
Left Powerplant	9	15W x 30H	45,000	1041.0
Right Powerplant	9	15W x 30H	45,000	1041.0
Third Powerplant	6	29W x 43.5H	210,000	1130.0
Banks pumping unit				
Pumps	6	14 ft diameter main	9,600	1193.3
Pump-generators	6	intake pipe	10,200	1193.3
River outlets (diameter)				
Upper	20	8.5	265,000 maximum for	1136.7
Mid	20	8.5	upper and mid tiers at	1036.7
Lower (3)	< 20 >	< 8.5 >	water elevation 1291.5	< 935.7 >
Spillway				variable from elevation
Drum gates	11	135L x 28H	1.0 million cfs	1288 to 1260

Notes: (1) Flow rate expressed in cubic feet per second (cfs or ft^3 /s). (2) Units of all elevations are expressed as feet above mean sea level (MSL). (3) River outlets removed from service with third powerhouse construction (Vermeyen, 2000).

Lake Roosevelt hydrology and operating factors—

Hydrologic characteristics of the reservoir including the total impounded water volume, inflow rates, and theoretical flow-through rates are shown in table 3-2. The actual flow-through rate cannot be determined from historic data, although the effective rate is expected to be somewhat lower than theoretical because of incomplete mixing and also could vary considerably at different times of the year due to annual drawdown and thermal stratification. Dam operations including intake depths and withdrawal rates could also modify stratification patterns, and actual effects of structural or operational changes on reservoir flow characteristics requires further study.

Table 3-2. Columbia River hydrologic characteristics and Lake Roosevelt operating conditions.

Flow rates for period of record 1914 to 2000 (1)	1956 minimum flow 1948 maximum flow Average flow rate	14,900 cubic feet per second (cfs) 637,800 cfs 109,200 cfs = 79,057,185 acre-ft / year
Volume and average theoretical flow-through residence time (2)	Max. operating pool el. 1290 ft. = Min. operating pool el. 1208 ft. =	9,500,000 acre-ft ~ 43.9 days 4,300,000 acre-ft ~ 19.9 days
Annual mean flow for period of record 1930 to 2000 (1)	Minimum 1944 (dry year) Maximum 1997 (wet year) Typical 2000 (mean flow)	71,150 cfs = 51.5 million acre-ft / year 147,800 cfs = 107 million acre-ft / year 113,400 cfs = 82.1 million acre-ft / year

Notes: (1) Hydrologic data for Columbia River at Grand Coulee Dam (USGS, 2000). (2) Theoretical residence time assumes complete mixed, plug-flow of entire reservoir volume indicated. (3) Average flow rates in feet per second (cfs)

Area-capacity curves for Grand Coulee Dam—

A data plot of the area-capacity (stage-volume) characteristics for Lake Roosevelt is shown in figure 3-2. This plot shows that more than one-half of the 9.5 million acre-feet (acre-ft) total reservoir volume is contained in the uppermost 80 feet of elevation, and is within the annual storage drawdown range. This has important implications for seasonal mixing and stratification patterns. For purposes of this review, the area-capacity curve provided a means to estimate the volume of water associated with selected depth ranges.

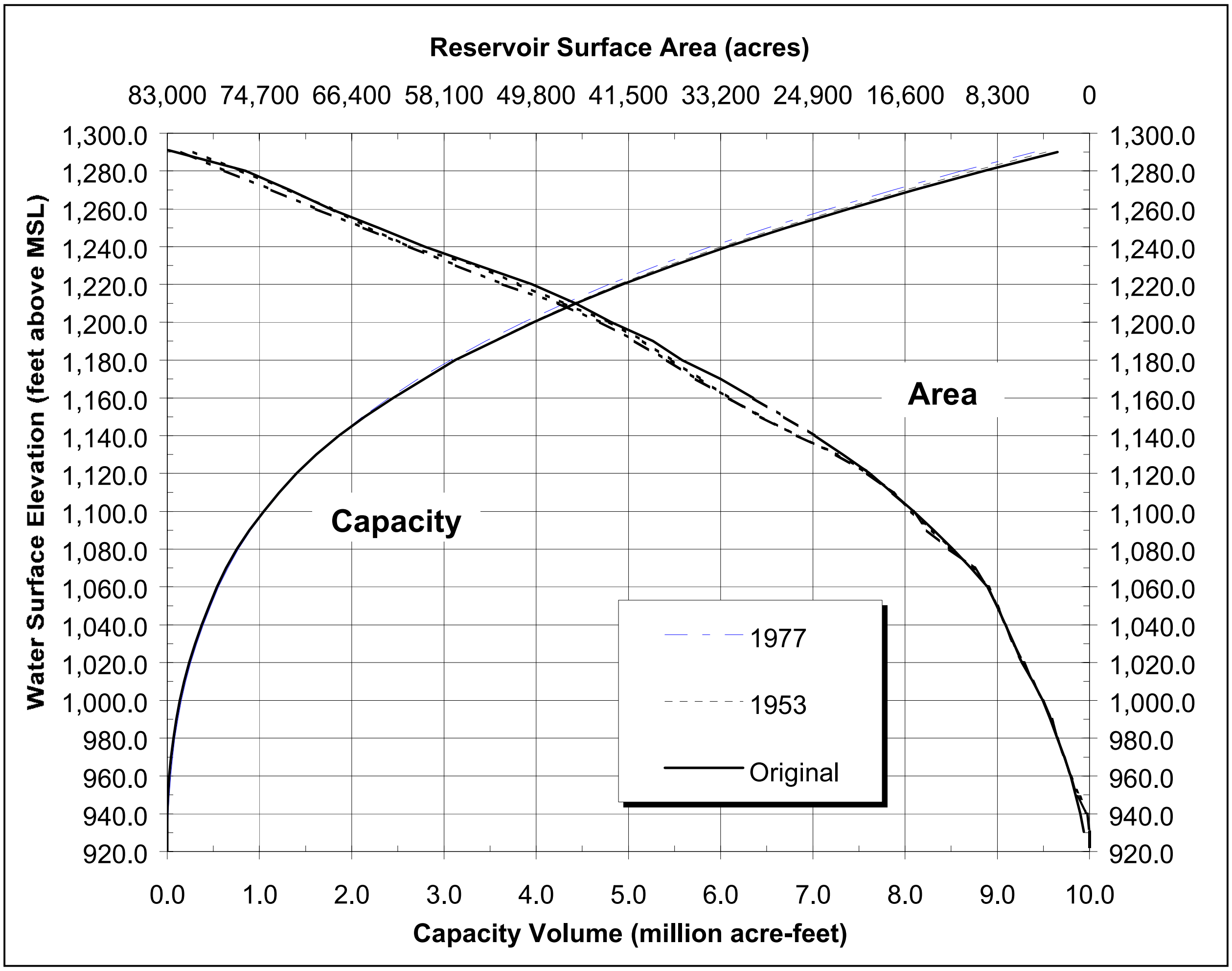


Figure 3-2. Area-capacity plots for available reservoir bathymetry data (Reclamation, 2003).

Note that the different curves shown on the area-capacity plot were based on an evaluation of the available reservoir bathymetry data (Reclamation, 2003). The curves illustrate graphically that very small shifts in the data can impart significant differences in water volumes and associated flow characteristics that are critical to accurately model reservoir hydrodynamic conditions and associated mechanisms that influence water quality and temperature characteristics at different times of the year, annual hydrologic variations, and reservoir operating conditions.

Temperature conditions in Columbia River upstream and downstream of Grand Coulee Dam—

Plots of water temperature data taken below the water surface at two Columbia River stations are shown in figure 3-3. One station is located near the international boundary (CIBW) and the other is located about six miles downstream of Grand Coulee Dam (GCGW). The plot shows a shift in annual temperature patterns in the downstream direction, indicating a dampening effect on water temperatures as the flow passes through Lake Roosevelt and Grand Coulee Dam. It also suggests that the seasonal elevated temperature problems downstream are attributed to heating processes, thermal stratification, and inherent seasonal time lag effects—important factors to consider in the ongoing TMDL planning and any alternatives conceived to modify temperature conditions.

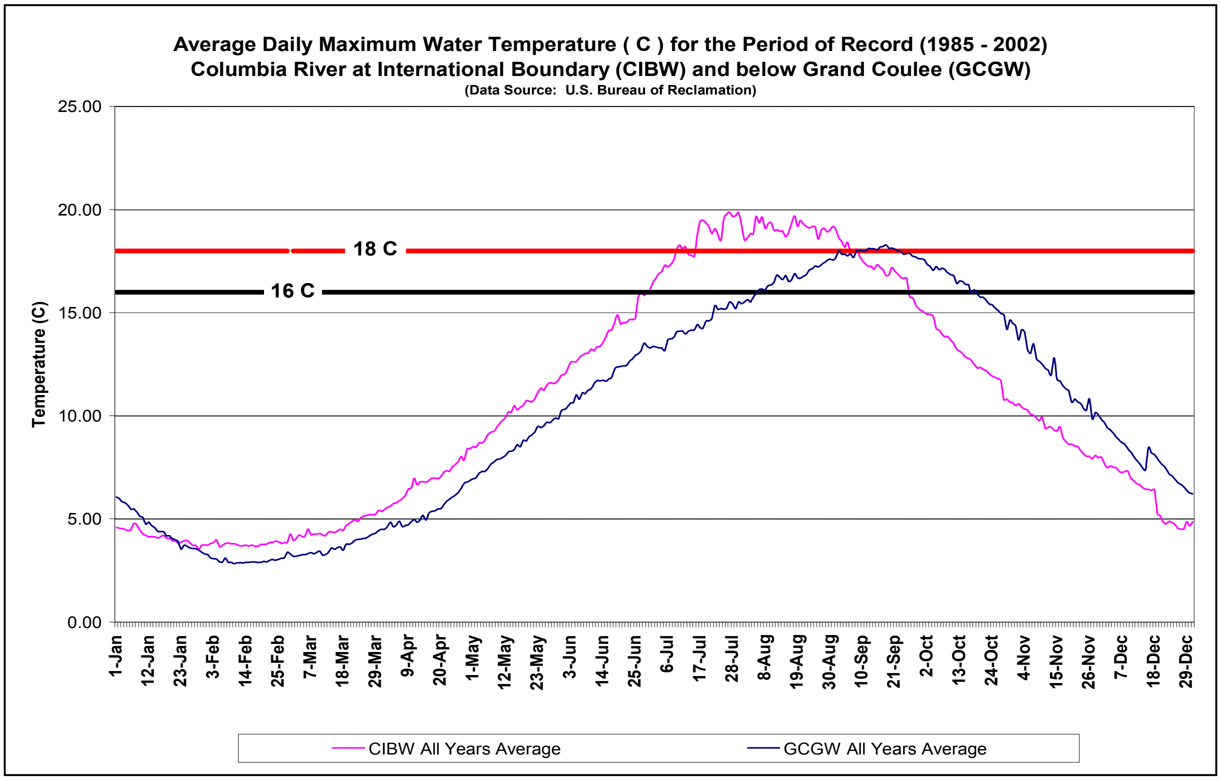


Figure 3-3. Average daily maximum water temperatures (1985 to 2002) in the Columbia River upstream at international boundary (CIBW) and downstream (GCGW) below Grand Coulee Dam.

Early in the year, the inflow (CIBW) data are above the outflow (GCGW) data, indicating a time lag in reservoir warming through the summer until the curves cross in early September, when a time lag in cooling occurs during the late summer and fall months. Annual reservoir drawdown, stratification, and changes in outflow rates attributed to snow pack and reservoir operations can all influence the internal hydrodynamic conditions occurring within Lake Roosevelt. As a result, the hydraulic efficiency of water passing through the reservoir may vary at different times of the year—particularly during periods of stratification if thermal gradients allow water to effectively slip through (interflow) faster within a layer of equal density.

Short term fluctuations in Grand Coulee Dam powerplant operations—

Flow rates through Grand Coulee Dam can vary widely over the daily 24-hour cycle depending on peak power demands. Total flow volume for a given day is subject to the river flow rates and the annual reservoir flood storage needs. However, within these daily totals, dam operations are also governed by power demands that typically rise in morning and evening hours as municipal and industrial power usage increases. In addition, air conditioning use in summer months and the reduced daylight hours in winter months also affect total peak power demands.

These trends are illustrated by the data plotted in figure 3-4, showing how Grand Coulee flow rates vary over the 24-hour daily cycle. Each curve shows hourly flow rates for the first day of the month taken at the mid-point of the four seasons for water years 1998 and 2000.

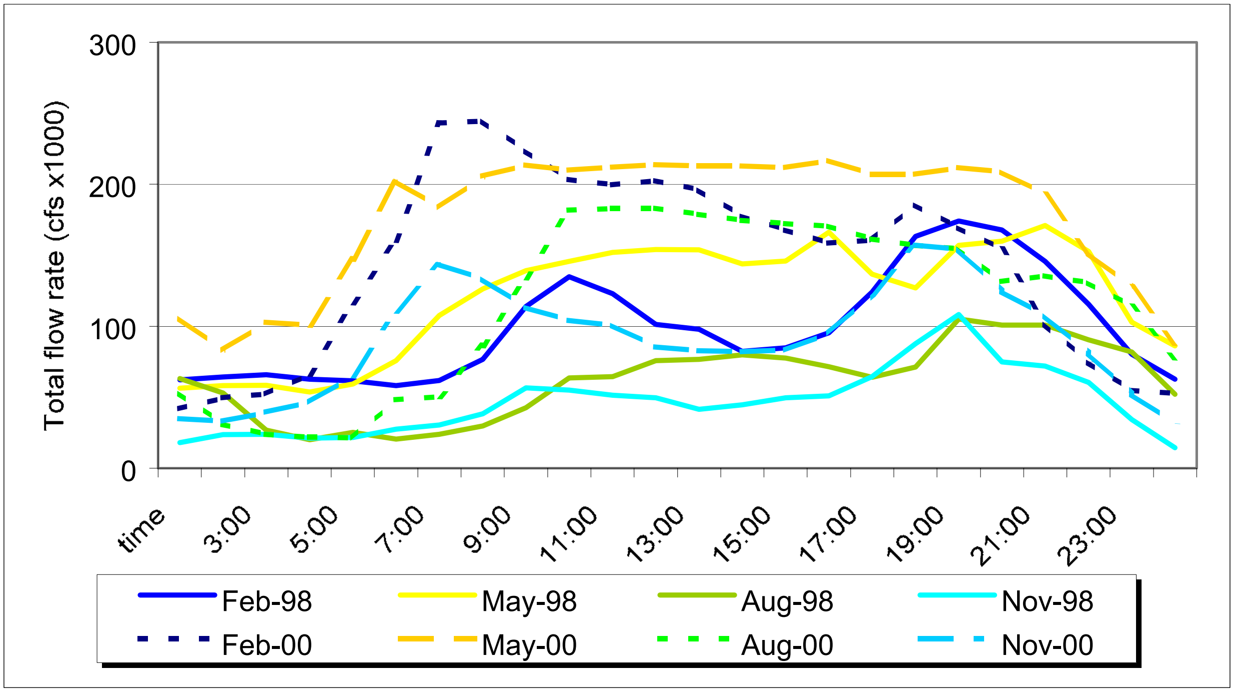


Figure 3-4. Grand Coulee total flow rates for one 24-hour cycle selected each quarter in 1998 and 2000 show annual and seasonal variations, and hourly operational changes to meet power demand.

Total average daily flows were used in this review to estimate potential benefits associated with modifying operations to reduce the release temperatures at Grand Coulee during critical summer and early fall time periods. This approach may over-state the potential for temperature reduction because the 90,000 cfs combined capacity of the Left and Right Powerplants would restrict the ability to make operational adjustments at certain times of the day. Power generation operating conditions are dynamic and could have significant implications on hydrodynamic conditions in the reservoir. Consequently, characterizing short and long term operational effects is important to understand existing interactions or to evaluate the effects of alternative operating strategies on downstream temperatures or conditions within the reservoir.

Thermal Stratification in Lake Roosevelt

Seasonal temperature stratification is common in reservoirs in temperate climate zones. Surface water that is warmed by solar radiation is lighter than cooler water, resulting in thermal density gradients that are often strong enough to resist mixing by wind, inflows, outflow, or reservoir currents. Cooler inflows will tend to sink to an elevation of equal water density and cold water stored during the winter remains at the deep reservoir bottom elevations. The volume of water and stability of colder hypolimnion and warmer epilimnion layers can be modified significantly by the hydraulic configuration and elevations of the dam outlets.

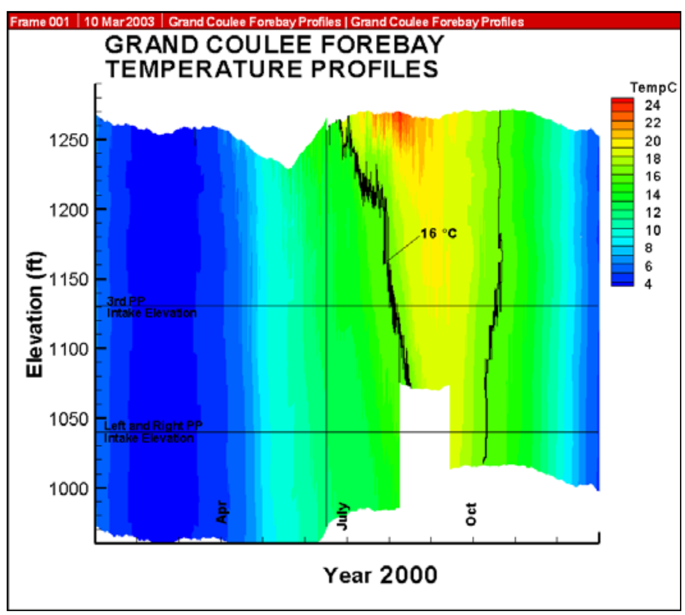
Stratification patterns in Lake Roosevelt have been examined by collecting temperature data at vertical depth intervals from the water surface down. Reclamation has a string of thermistors about 100 meters long suspended in the Grand Coulee forebay, a few hundred feet upstream of the dam. The thermistor string provides data every 15-minutes for the full range depth intervals to give a detailed record of temperature conditions in the forebay area. The staff members of the Spokane Tribe of Indians have also collected a significant amount of temperature profile data to monitor conditions at various locations throughout Lake Roosevelt.

Plots of temperature profile data collected to date are included in the appendices. These vertical profiles provide insight into conditions at a given time. Different types of profile data were used to assess the temperature management options considered in this review.

Temperature stratification at Grand Coulee forebay—

- *Appendix A. Vertical temperature profiles, Grand Coulee forebay, 1998-2002*

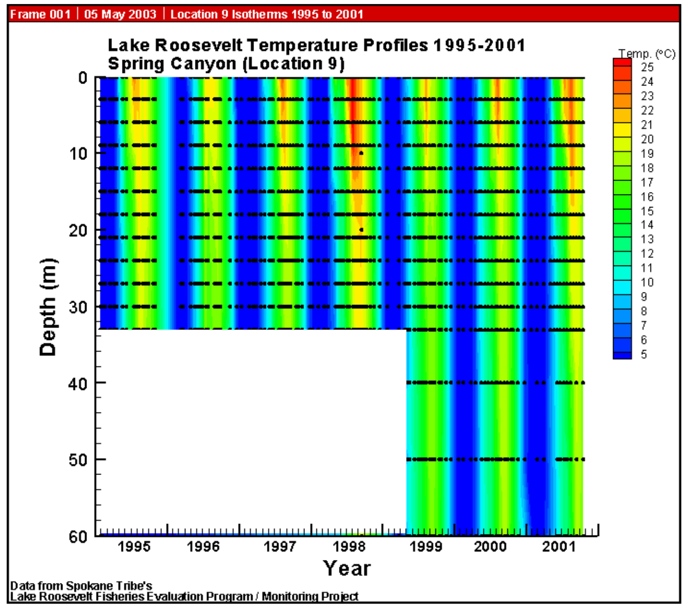
These vertical profiles show the extent and duration of thermal stratification in the forebay area. Annual drawdown for flood storage is evident by the variations in the surface elevation. Black lines were added to show powerplant intake elevations and the 16 ˚C temperature criteria within the annual patterns. The stratification period of about 90 days is apparent in these data plots. The profile plots and area capacity curves give an idea of the duration and water volume available for temperature management, but this instantaneous view does not indicate how temperatures or the hydrodynamic properties could respond to changes in reservoir operations.



Annual temperature variations in Lake Roosevelt—

- *Appendix B. Continuous vertical temperature profiles for 1998 through 2001; Spring Canyon, Site ST-9; Spokane River, Site ST-4; Hunters, Site ST-3; Gifford Site, ST-2; and Kettle Falls, Site ST-1.*

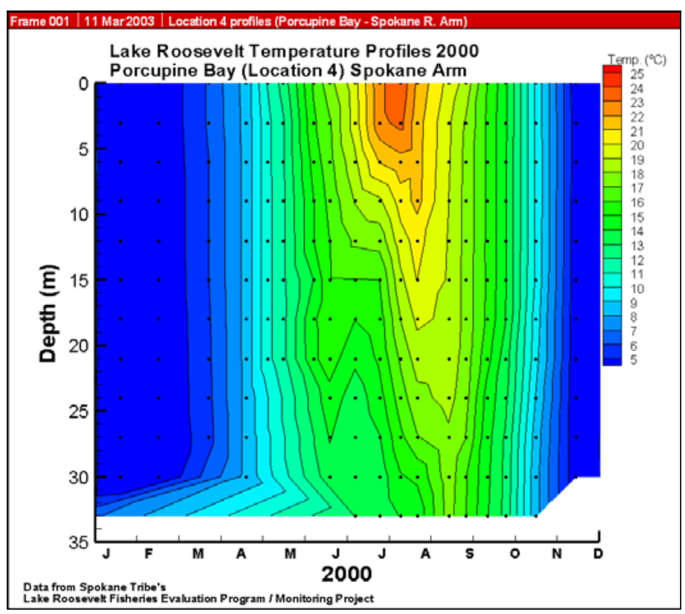
Continuous temperature profiles show how thermal stratification patterns can change by water year or climate conditions. Data plots are included for five sites in Lake Roosevelt from data collected by the Spokane Tribe of Indians. Water years 1998 to 2001 were all within 15 percent of normal precipitation, but 1998 was a year of exceptionally hot climate conditions. Year 1997, the highest average flow on record, apparently did not alter stratification appreciably. Profiles at upstream sites indicate stratification above the Spokane River inflow diminishes and becomes almost non-existent in the upper reservoir at Kettle Falls (appendix B).



Spatial stratification patterns in upper Lake Roosevelt—

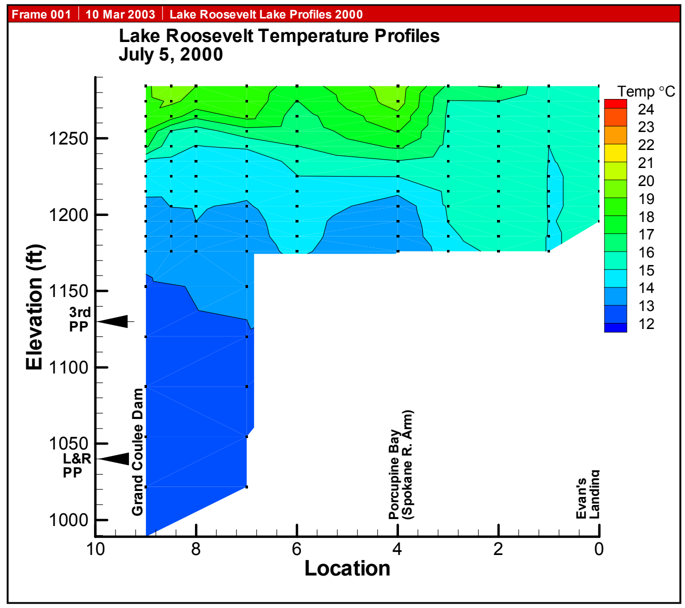
- *Appendix B. Temperature profiles, water year 2000; Spokane River, Site ST-4; Hunters, Site ST-3; and Kettle Falls, Site ST-1.*

Profile plots for a single site and typical water year 2000 provide a more detailed view of conditions in the upper reservoir reaches. Stratification is stronger at the Spokane River site, ST-4, and is absent at Kettle Falls site, ST-1 at the upstream end of the reservoir. The reservoir below the Spokane River is much deeper and wider, with slower flow velocities that are more conducive to allow stratification, whereas upper reaches of the reservoir are more likely to be dominated by temperatures of the relatively rapidly exchanged inflow water. The duration of stratification also diminishes upstream, further reflecting the transient seasonal conditions.



Longitudinal temperature profile changes over time—

- *Appendix C. Longitudinal profiles for Lake Roosevelt, 1998, all sites, 6 dates*
- *Appendix C. Longitudinal profiles for Lake Roosevelt, 2000, all sites, 8 dates*



Composite longitudinal temperature plots were developed by combining the vertical profile data collected at the Grand Coulee forebay with profiles collected at upstream points in Lake Roosevelt. These profiles show how temperature conditions change through the reservoir. Discontinuity in the plot at ST-4 occurs because the station is actually located at Porcupine Bay on the Spokane River arm of Lake Roosevelt. Profiles collected for different dates show how the conditions change during the late summer of 1998 and 2000. In particular, in mid-October the inflow temperatures start to drop back to within standards, but the cooler water has not yet reached the reservoir outlet. The water mass-balance and effective travel time are key factors to assess thermal heating and hydrodynamic effects on reservoir temperatures. The actual travel time can vary substantially from theoretical residence time that assumes complete mixing and plug-flow conditions. Thermal stratification can produce interflows where water of given temperature effectively slips through more rapidly by displacing only the water of equal density in layers that are within a similar temperature range.

River and Reservoir Temperature Modeling

Mechanistic models used to simulate temperature conditions and other water quality parameters in rivers and reservoirs vary in their complexity and data requirements. One or two-dimensional models are most common, although 3-d models have been developed to examine complicated systems in greater detail. In selecting models, the available data and resource requirements are weighed against the level of detail and accuracy appropriate to address specific circumstances of the system modeled. For example, a 1-d model may be adequate for screening purposes, to gain insight into trends within large systems, or to evaluate processes under relatively simple, uniform conditions. Two-dimensional models are widely applied to evaluate temperature in reservoirs that are seasonally stratified or have moderate hydrodynamic complexity. Although 3-d models are more readily supported by advanced computer technology, the data required and scientific basis are typically more intensive. Data collection, uncertainty analysis, and appropriate model application are important topics of discussion for the TMDL process (NRC, 2001).

Existing temperature conditions, site potential determinations, and target temperature allocation in the draft TMDL (EPA, 2002b) are based on a 1-d heat model (Yearsley et al, 2001) developed to simulate temperatures through the Columbia River mainstem. The 1-d model calculations are based on average conditions for each cross-section used to define river segments. This approach is advantageous to reduce data needs and simplify the analysis for the entire mainstem river and 11 reservoirs, although it also has certain limitations. Implications of using daily cross-sectional average temperatures in the 1-d model simulations are discussed in the draft TMDL.

Vertical temperature profiles collected at Lake Roosevelt clearly show the stratification patterns that occur seasonally in the reservoir (Appendix A and B). In addition, longitudinal temperature gradients vary seasonally (Appendix C) and could indicate mixing and interflow effects. Internal reservoir processes such as thermal stratification, interflow currents, density gradients, wind, and other non-uniform hydrodynamic conditions require analysis of variations of time and exchanges that occur with depth. In recent years, new meteorology stations were installed at locations near Lake Roosevelt and monitoring efforts have been continuously improved to obtain accurate data (reservoir bathymetry, meteorology, water temperature, and flow data) that is essential to support sound investigations and simulation modeling of reservoir processes.

EPA developed a 2-d hydrodynamic temperature model for Lake Roosevelt (Yearsley, 2003) using CE-QUAL-W2 Version 2.0 (COE, 1995) based on the data available. The original model capabilities have been updated and expanded to Version 3.1 (Cole, T.M. and S.A. Wells, 2002), and in particular, it now accommodates multiple waterbodies in the same computational grid; including multiple reservoirs with sloping river sections between reservoirs. The basic model construct can also compute a withdrawal zone for selected outlet geometry, outflow rates, and reservoir density gradients (stratification).

This type of 2-d reservoir model would be useful to characterize the hydrodynamic conditions in Lake Roosevelt that can influence downstream water temperatures under existing conditions and accurately predict the impacts of different management alternatives. Although some areas of the reservoir may have conditions that vary laterally, undertaking a complete 3-d modeling effort for Lake Roosevelt would be prohibitively expensive and unnecessary. Although the configuration and operating conditions in the Grand Coulee forebay area are complicated, it appears that this could be addressed practically by adapting a 2-d analysis approach to focus on certain attributes in the model construct to assemble a composite view of characteristics of interest.

Overall, this initial review of temperature data for Lake Roosevelt shows the thermal variations with depth and dynamic conditions over time. Statistical analysis and mechanistic 1-d models can help to understand conditions in the reservoir based on historic data, but are not adequate to characterize the transient hydrodynamic conditions. Perhaps more importantly, simple model analysis techniques cannot accurately predict the impacts (or costs) of structural or operational actions that produce significant changes in the system processes. Moreover, even if technically feasible, a 3-d modeling approach may be exceedingly complicated and expensive. A 2-d model approach such as CE-QUAL-W2 appears to offer the most cost-effective and practical means to characterize the existing reservoir processes and evaluate potential alternatives.

4.0 Optional Strategy 1 — Modify operations at the left, right, and third powerplants

This option involves shifting power generation loads between the Left (L), Right (R), and Third (3^{rd}) Powerplants (PP) at Grand Coulee using only operational changes without modifications to the existing facilities. A simplified analysis was completed using mass-balance calculations with no external heat gains or losses. Vertical temperature profiles at the Grand Coulee forebay and the reservoir area-capacity curves were used to estimate the water volumes and duration for PP operations. A previous study was also reviewed (Vermeyen, 2000) to determine whether a 1-d selective withdrawal model (SELECT) could be used to evaluate temperature effects associated with the three existing PP intake elevations at Grand Coulee Dam.

Temperature Management Strategy

The existing Left and Right Powerplant intake elevations are about 89 feet lower than the 3^{rd} PP intakes. This strategy would take advantage of the different intake elevations to access warmer or colder water layers during the seasonal period of stratification.

- Use the 3^{rd} PP during early summer months to conserve cold water and minimize warm water accumulation in the reservoir until releases exceed 16 ˚C.
- When GCGW (downstream) temperatures exceed 16 ˚C, begin shifting generation loads to the Left and Right PP's to maintain 16 ˚C releases. Continue shifting loads until Left and Right PP flows are maximized, and no further temperature reduction is possible.
- Maintain maximum Left and Right PP releases until GCGW temperatures drop back to below 16 ˚C and then begin shifting power loads to 3rd PP as the reservoir cools.
- Optimize this strategy within hourly peaking requirements and to take advantage of daily cycles that could enhance temperature benefits (requires additional review).

Option 1 Results

Potential temperature improvement benefits—

Results of this basic analysis indicated that shifting power generation between the Left and Right Powerplants and the 3^{rd} PP could maintain release temperatures at 16 ˚C for 17 to 24 days based on data for years 2000 and 2001. However, the release temperatures would still exceed the 16 ˚C criteria for an estimated 71 days in 2000 and 63 days for 2001. These temperature benefits may be over-stated because hourly adjustments required to meet the actual peak power demands could restrict the ability to shift power operations at certain times of the day. In addition, the effective duration of temperature management and efficiency of withdrawing water from different layers depends on the actual hydrodynamic conditions in the reservoir. These conditions are uncertain and may respond to a number of variables including operational changes, annual drawdown, and the ambient snow pack or climate conditions for a given year. Moreover, this option provides no benefit during fall or winter months when there is no thermal stratification in the reservoir.

Operational costs and cost factors—

Costs of operational changes to existing facilities are difficult to quantify at this level of review because cost factors such as incremental power generation efficiency or long term maintenance considerations are more subtle and require much more detailed information. In this case, minor costs are expected for shifting power between the three powerplants, if the total power generation rates are retained. Consequently, the costs of this operational temperature management strategy would be relatively low. Costs attributed to long-term operations and maintenance requirements or reduced generation efficiency will require more detailed review.

Analysis and Discussion

Simplified analyses were completed using data for 2000 and 2001 to estimate the temperature benefits associated with this management strategy. Operational changes would require shifting power generation between the Left and Right PP's (separately or combined), and the 3rd PP to control release water temperatures. The analysis completed for this initial review was based on simplifying assumptions including:

- Average daily temperatures at the GCGW monitoring site are the same as Grand Coulee powerplants releases (i.e. assumes that no significant warming occurs in the 6-mile river reach between the dam outlet and GCGW).
- Most of the release flow from Grand Coulee was assumed to be from the 3rd PP, then as cooler releases are needed, generation can be shifted to the Left and Right Powerplants up to the total maximum flow rate of 90,000 cubic feet per second (90 Kcfs).
- Vertical water temperature profile data taken at the Grand Coulee forebay reflects actual intake temperatures at elevation 1041 for the Left and Right PP's, and elevation 1130 for the 3rd PP. All elevations are expressed as feet above mean sea level (MSL).
- For year 2000, missing temperature data (appendix A) were estimated by interpolating the 16 ˚C contour for 10 days prior to the period from August 8 to September 13, 2000.
- The ability to shift loads between powerplants is adequately represented by daily average flows and is not impacted by peak power operations. This assumption could overestimate benefits, but analyzing hourly operations data was not practical for this review.
- The analysis assumes that the operational strategy will not alter the temperature profiles or volume of cooler or warmer water layers. Simulation modeling is required to evaluate how reservoir thermal stratification patterns respond to operational changes that modify the way that water is withdrawn from the reservoir pool.

Previous selective withdrawal studies for Grand Coulee Dam—

Predicting the selective withdrawal properties for a reservoir is helpful to evaluate design plans or the operational efficiency of proposed facilities. A previous model study using a 1-d selective withdrawal calculation model was reviewed to determine whether the results could be adapted to evaluate temperature effects associated with the different intake elevations of the three existing Grand Coulee powerplants considered in this strategy.

Significant research has been conducted on thermal stratification and withdrawal characteristics for reservoirs and the U.S. Army Corps of Engineers has derived empirical equations to describe the vertical withdrawal zone and velocity profiles that develop near the submerged intakes of a stratified reservoir. These equations were used to develop a 1-d selective withdrawal model called SELECT (COE, 1987). The SELECT model can be used to determine withdrawal limits and velocity profiles for a given reservoir temperature profile. For this review, the model was adapted to estimate release temperatures associated with shifting operations between the 3rd PP and the Left and Right PP's as described in the management strategy.

The SELECT model was run using forebay temperature profile data collected by Reclamation on several days in 1998 and 1999 (Vermeyen 2000). Release temperatures were examined for the three Grand Coulee Dam powerplants and the Banks Lake Pump-generators. Model runs for the 3rd PP produced significantly lower temperatures than the measured data at the GCGW station, indicating the SELECT model cannot accurately reproduce selective withdrawal characteristics for the 3rd PP approach channel. The invert of the approach channel is at elevation 1110 ft and the intake centerline elevation is 1130 ft. To compute release temperatures for the 3rd PP that matched the GCGW temperatures, the intake elevation input in the model had to be adjusted 70 to 80 feet higher. This error is not unusual considering the empirical equations that describe selective withdrawal were developed assuming an infinite reservoir pool volume and relatively small intake dimensions without vertical or lateral restrictions. The restricted approach channel to the 3rd PP does not comply with these assumptions, and consequently, the SELECT model was not used further in estimating temperature effects for this analysis.

Effective reservoir volume analysis—

Lake Roosevelt area-capacity curves (figure 3-2) indicate that about 1.2 million acre-ft of water is stored between the 3rd PP intake elevation 1130 and elevation 1041 for the Left and Right PP intakes. There is also about 400,000 acre-ft additional volume below elevation 1041. Given that the total reservoir storage capacity is over 9 million acre-ft at elevation 1290, about 87 percent of the storage volume is above the 3rd PP intakes. During thermal stratification, temperatures at a given depth tend to vary spatially from the dam upstream. For example, temperatures measured on July 7, 2000 at CIBW (International Boundary) were about 2.8 ˚C warmer than downstream at GCGW (below Grand Coulee). The vertical extent of water accessed by the intakes could also vary depending on flow rates and duration of withdrawals. Despite this limitation, these volume estimates were used to evaluate the effective duration of temperature control operations.

Columbia River inflow and outflow temperature analysis—

Average daily temperature data collected at the International Boundary (CIBW), Grand Coulee tailrace (GCGW), and Chief Joseph Dam (CHQW) are presented in figure 4-1. This illustrates the time lag as water flows downstream. Temperatures rise above 16 ˚C by about July 3rd at the CIBW site and around July 10th to 20th at GCGW. The time lag increases later in the year as the temperatures upstream at CIBW decrease in August and September, and temperatures at GCGW start to drop later and are back to 16 ˚C again by late October.

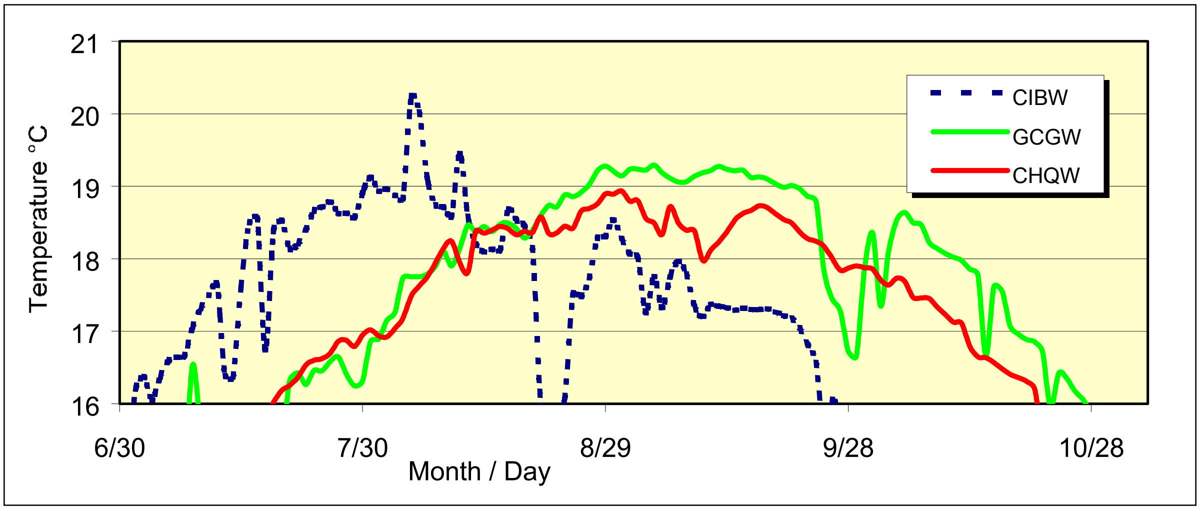


Figure 4-1. Average water temperature from 1998 to 2002 at International boundary (CIBW), the Grand Coulee Dam tailrace (GCGW), and below Chief Joseph Dam (CHQW).

Each spring, the reservoir is refilled and reaches full pool by early July when inflow temperatures are rising. In the fall, it can take longer for temperatures to drop back at GCGW because outflow rates are typically lower (figure 4-2) resulting in more time required to release warmer water that has accumulated in Lake Roosevelt. In addition, at times of reduced outflow, less water is released from the Left and Right Powerplants that have deeper intakes, so it may take longer for cool water flowing into the reservoir to displace the warmer upper water volume released through the 3rd Powerplant.

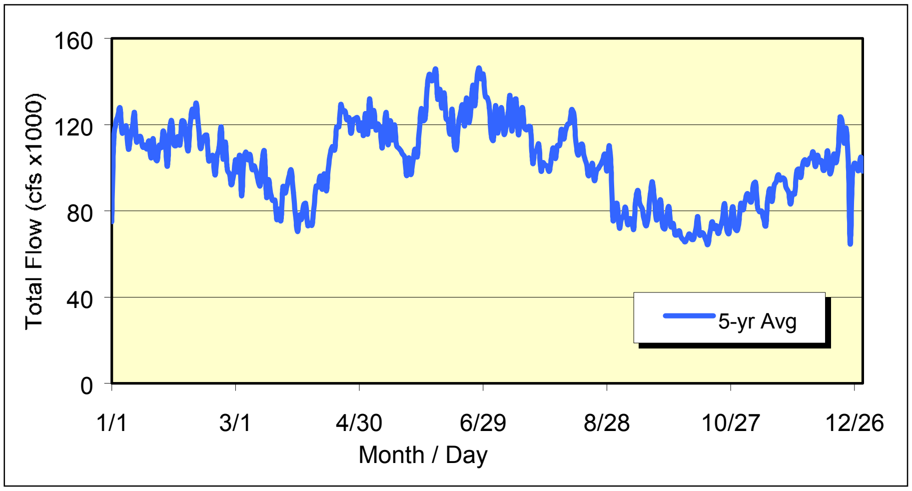


Figure 4-2. Grand Coulee Dam average outflow rates for 1998 to 2002.

Release water temperature management calculations—

Average daily water temperatures at GCGW exceeded the 16 ˚C criteria for a total of 88 days from July 19 through October 14, 2000. However, reservoir temperatures at the 1130 elevation of the 3rd PP intakes were still below 16 ˚C until August 5, so the ability to shift operations to the Left and Right PP's to tap into cooler water would not be effective for that period. This analysis used August 5th as the beginning of temperature control operations to start incrementally shifting the power generation to maintain the 16 ˚C criteria. Downstream temperatures for year 2000 and resulting flow rates, flow distribution, and water volumes are shown in table 4-1.

Table 4-1. Summary of Grand Coulee Dam daily flow distribution between the 3rd Powerplant and the Left and Right Powerplants to achieve 16 ºC release temperatures based on year 2000 data.

DATE	GCGW (˚C)	GCL Q (KCFS)	3rd PP (KCFS)	L&R PP (KCFS)	Release Temp (˚C)	L&R PP % of Total Q	L&R Volume (Acre-ft)
08/05/00	17.98	124.6	94.1	30.5	16.0	24%	60,497
08/06/00	17.97	98.8	98.8	0	16.0	0%	0
08/07/00	17.97	101.6	101.6	0	16.0	0%	0
08/08/00	18.44	118.9	94.9	24	16.0	20%	47,604
08/09/00	18.52	124.8	78.8	46	16.0	37%	91,241
08/10/00	18.79	145.3	98.3	47	16.0	32%	93,225
08/11/00	18.59	149.1	86.1	63	16.0	42%	124,961
08/12/00	18.68	122.6	51.6	71	16.0	58%	140,829
08/13/00	18.5	117.3	37.3	80	16.0	68%	158,680
08/14/00	18.27	102.8	27.8	75	16.0	73%	148,763
08/15/00	18.47	125.8	32.8	93	16.0	74%	184,466
08/16/00	18.76	130.8	27.8	103	16.0	79%	204,301
08/17/00	18.7	124.3	16.6	107.7	15.9	87%	213,623
08/18/00	18.94	124.6	12.6	112	16.0	90%	222,152
08/19/00	18.82	92.0	6.0	86	16.0	93%	170,581
08/20/00	16.72	51.4	1.9	49.5	16.0	96%	98,183
08/21/00	17.79	70.0	0	70	16.0	100%	138,845
08/22/00	18.5	84.3	0	84.3	16.1	100%	167,209

Note: The 16 ˚C criteria temperature was a reference for this analysis. Site potential temperatures cited in the current draft TMDL were not available for this review. Flow rates (Q) are in thousand cubic feet per second (Kcfs).

This basic analysis indicated there is a maximum 17-day opportunity to maintain 16 ˚C releases using the operational strategy. The effective duration was based on the time required to release an estimated 2.3 million acre-ft of colder water using the Left and Right Powerplants. Median temperature reduction during this period is 2.5 ˚C for year 2000 data. After August 22, release temperatures would exceed 16 ˚C, but could be reduced by allocating as much flow as possible through the Left and Right Powerplants. This operation would continue until fall when cooler inflows are available for release using the 3rd Powerplant.

For 2001, a similar analysis of GCGW temperatures show that from August 5th to October 30th the river temperatures exceeded 16 ˚C for a total of 87 days. August 14th was used for the start of temperature control operations to shift power generation incrementally between the 3rd PP, and the Left and Right PP's to maintain the 16 ˚C criteria. Downstream temperatures, water volume, resulting flow rates, and flow distribution for year 2001 data are shown in table 4-2.

Table 4-2. Summary of Grand Coulee Dam daily flow distribution between the 3rd Powerplant and the Left and Right Powerplants to achieve 16 ºC release temperatures based on year 2001 data.

DATE	GCGW (˚C)	GCL Q (KCFS)	3rd PP (KCFS)	L&R PP (KCFS)	Release Temp (˚C)	L&R PP % of Total Q	L&R Volume (Acre-ft)
08/14/01	16.3	80.6	71.0	9.6	16.0	12%	19,042
08/15/01	17.0	81.6	81.0	0.6	15.98	1%	1,190
08/16/01	16.8	75.0	60.0	15.0	16.01	20%	29,752
08/17/01	17.0	82.4	53.4	29.0	16.00	35%	57,521
08/18/01	16.8	57.9	35.9	22.0	16.00	38%	43,637
08/19/01	17.0	41.7	26.2	15.5	15.99	37%	30,744
08/20/01	16.4	69.7	53.2	16.5	16.01	24%	32,728
08/21/01	16.8	63.1	42.1	21.0	16.02	33%	41,654
08/22/01	17.6	59.4	31.4	28.0	16.00	47%	55,538
08/23/01	16.8	67.3	30.8	36.5	16.01	54%	72,398
08/24/01	17.3	78.3	28.3	50.0	16.00	64%	99,175
08/25/01	17.5	70.7	26.7	44.0	16.00	62%	87,274
08/26/01	17.6	63.6	24.1	39.5	16.01	62%	78,349
08/27/01	17.9	103.2	25.2	78.0	15.99	76%	154,713
08/28/01	18.0	84.8	22.8	62.0	16.00	73%	122,977
08/29/01	18.2	71.6	16.6	55.0	16.02	77%	109,092
08/30/01	17.9	90.0	18.0	72.0	16.02	80%	142,812
08/31/01	17.7	72.5	6.5	66.0	15.99	91%	130,911
09/01/01	18.2	48.3	4.3	44.0	16.03	91%	87,274
09/02/01	18.5	51.8	0.8	51.0	16.06	98%	101,159
09/03/01	18.2	67.5	5.5	62.0	16.02	92%	122,977
09/04/01	18.2	81.8	4.8	77.0	16.02	94%	152,729
09/05/01	17.8	68.0	0	68.0	16.32	100%	134,878

Note: The 16 ˚C criteria temperature was a reference for this analysis. Site potential temperatures cited in the current draft TMDL were not available for this review. Flow rates (Q) are in thousand cubic feet per second (Kcfs).

For this case, it appears there is a maximum 24-day opportunity to effectively regulate release temperatures at the 16 ˚C criteria, followed by a period of potential temperature reduction above the criteria as described previously. Median temperature reduction was 1.6 ˚C over the 24-days of temperature management, and during this period the estimated 1.9 million acre-ft of available cool water would be released through Left and Right PP's based on data for year 2001. Under the actual operating conditions, GCGW water temperatures dropped back below 16 ˚C on October 15, 2000 and October 31, 2001. However, evacuation of cooler water layers could alter the effective reservoir flow-through rate and the corresponding cooling in the fall. Removing the warmer upper reservoir water could also affect temperatures in the reservoir and the downstream river. Projections of the effective magnitude and duration of temperature management could be refined by using more detailed hourly operational data to represent the flows through each of the separate powerplants and generator units at Grand Coulee.

Climate conditions, watershed hydrology, reservoir operations, hydrodynamics, and temperature conditions are all interrelated. Changes in reservoir operations could influence the productivity that supports dependent fish, bird, and animal communities. These interactions in the reservoir can offer additional management opportunities; however, more detailed analysis and simulation modeling is required to characterize existing conditions and evaluate how alternatives are linked to critical process relationships and other related resource implications.

Also note that this analysis used the 16 ˚C maximum water temperature criteria as an initial point of reference. Additional analysis is necessary to evaluate temperature strategies with respect to the current draft TMDL, site potential temperature allocations, or other temperature criteria that may be forthcoming from the TMDL planning process.

5.0 Optional Strategy 2 — Install multi-level intakes on left and right powerplants

Existing powerplants at Grand Coulee could be modified by adding multi-level intake structures to allow for selective withdrawal of water at different depths. This analysis focused on deriving a rough estimate of the capital costs to construct selective withdrawal structures for the Left and Right Powerplants. Modifications to the 3rd PP were not considered because of the restricted approach channel and large scale expense factors expected. Structure dimensions were derived from a basic layout of full-height selective intake towers for the Left and Right Powerplants and the overall sizing parameters and cost factors were reviewed with respect to similar temperature control structures installed recently at Shasta Dam in California. Cost worksheets were prepared to estimate costs at a sub-appraisal level for major structural modification components.

Temperature Management Strategy

- In late June, begin using selective withdrawal at Left and Right PP's in surface withdrawal mode to evacuate warmer surface water and conserve more of the cold water pool.
- When Left and Right PP surface withdrawal temperatures exceed 16 ˚C, begin shifting load back to 3rd PP to maintain 16 ˚C releases and conserve the cooler water.
- When 16 ˚C can no longer be achieved using the 3rd PP, start shifting the power loads back to the Left and Right PP selective withdrawal structures with the intakes adjusted for low-level withdrawal. This can be done in stages using lower intakes and increasing flows.
- First, access colder water using pressure the relief gates at elevation 1041, then shift to lower gates near the reservoir bottom as required to maintain release temperatures. Lower elevation release rates could be increased up to the maximum total Left and Right PP capacity.
- When the 16 ˚C temperature criteria is not met, continue maximum total Left and Right PP releases to achieve some lesser temperature reduction, then later in the fall as reservoir water cools, shift loads back to the 3rd PP as possible to maintain temperature criteria.

Option 2 Results

Potential temperature improvement benefits—

Temperature improvement benefits for this option cannot be accurately determined by direct data analysis because historic data do not represent the modified facilities. Simulation modeling can produce reasonably accurate predictions of conditions associated with multi-level selective intake structures installed. However, when compared to the first strategy, these structural modifications are expected to provide greater efficiency and operational flexibility.

Multilevel intake structures have proven effective for a number of installations. Other apparent advantages of using selective withdrawal structures include the ability to manage temperatures over a longer period of time each year and the flexibility to balance downstream objectives with conditions in the reservoir. For example, accessing the additional 400,000 acre-ft of water below elevation 1041 would extend the period of cool water operations for about 3 to 4 days (based on total average daily flow rates at the end of August of about 50,000 to 80,000 cfs).

Pre-appraisal estimated structural costs—

Total estimated costs to construct multi-level intake structures at Grand Coulee Dam including 20 percent unlisted items and 25 percent contingencies and calendar year 2003 unit prices:

- Full-height selective withdrawal intakes for the Left Powerplant: $270 million.
- Full-height selective withdrawal intakes for the Right Powerplant: $250 million.

It may be possible to manage release temperatures effectively by constructing multi-level intakes at only one of the two original powerplants—most likely the left side where the intake approach is deeper. Operating flow rates and water volumes require further analysis to accurately project the effectiveness of selective withdrawal at each powerplant.

These preliminary estimates only reflect capital construction costs. Operational cost factors such as changes in generation efficiency or long-term maintenance were not evaluated. For example, selective withdrawal structures typically produce additional head loss. In addition, the feasibility of operating both the Left and Right Powerplants continuously at nearly peak capacity for much of the summer months would require further study.

Analysis and Discussion

Engineering requirements and corresponding economic factors associated with multi-level intake structures are primary considerations that influence the overall feasibility of this strategy. Basic information and assumptions were applied to derive preliminary cost estimates.

- Cost ranges are considered rough, sub-appraisal level estimates based on major features, cost factors, and experience from similar Reclamation projects.
- Basic layout of multi-level intakes assumes full height structures are necessary to tap into warmer water above and colder water below current penstock intake elevations.
- Costs of multi-level intakes for the Left and Right Powerplants at Grand Coulee Dam were reviewed with respect to the Shasta Dam Temperature Control Device.
- Operational costs and temperature benefits require additional study including simulation modeling to assess potential implications of shifting power operations to accommodate selective withdrawal objectives and coordinate the complicated array of hourly, daily, seasonal, and long-term reservoir operational needs.

Comparison with Shasta Temperature Control Device—

Multi-level intake structures for this option were modeled after the temperature control device installed at Shasta Dam in 1997 and sized proportionally to enclose the nine Left PP and nine Right PP intakes. These shutter structures are steel truss structures attached to the upstream face of the dam that enclose the existing penstock intake trashrack structures. A comparison of the Shasta Dam and Grand Coulee Dam structural features is shown in table 5-1.

The difference in intake spacing noted in the table is significant. Shasta Dam has five intakes with individual steel shutter structures placed around the trashrack structures for units 1, 3, and 5. After these structures were installed structural members, cladding, gates, and trashracks, were installed between them in front of existing trashrack structures 2 and 4. Because of the 65-foot intake spacing and proposed 55-foot wide shutter structures at Grand Coulee Dam, individual steel shutter structures were assumed for each intake.

Table 5-1. Comparison of Shasta and Grand Coulee powerplant features showing the relative scale factors used in rough estimate of selective withdrawal intake shutters dimensions.

FEATURE	SHASTA DAM POWERPLANT	GRAND COULEE DAM LEFT & RIGHT POWERPLANTS
Flow Q_{UNIT}	3,900 ft^3/s	5,000 ft^3/s
Type of PP Operation	Peaking	Peaking
Temperature Operation	Overdraw and Underdraw	Overdraw and Underdraw
Number of Intake Units	5	18
Center-to-Center Intake Spacing	50 ft.	65 ft.
Top of Dam to Centerline Intake	262 ft.	270 ft.
Trashrack Projection from Dam	26.5 ft.	26.5 ft.
Top of Trashracks (above intake centerline)	82 ft.	247 ft.
Width of Shutters	46 ft.	55 ft.
Height of Shutters	288 to 320 ft.	310 to 445 ft.

The purpose of the shutter structures is to optimize temperature management by allowing water withdrawal from selected levels of the reservoir. The shutters permit skimming of warm surface water, conservation of the colder water pool, and access to cold water that is currently below the withdrawal zone of the existing intakes at elevation 1041. Conserving the pool of cold water is achieved by forcing withdrawal from the highest elevation possible. To that end, upper shutter gates, middle shutter gates, or the lower pressure relief gates would be operated to access the highest permissible level based on the reservoir water surface elevation. To access cold water below the existing intakes, the shutters would be extended down to about 30 feet from the bottom of the reservoir and low level gates installed where practical.

Basic structural cost factors—

Each structure for the Left PP would be approximately 55 feet wide (cross canyon direction) by 50 feet deep (stream direction), and 385 feet high. For the Right PP, the width and depth would be the same but the shutters for units 10, 11, and 12 would be 445 feet high, units 13, 14 and 15 would be 355 feet high, and units 16, 17 and 18 would be 310 feet high according to the bottom topography below the intakes. The new multi-level intake structures would be suspended from a rigid frame (knee-braced support) attached to the dam at centerline elevation 1305. A hoist deck would be provided at the top of each structure at elevation 1310. A shutter structure would be provided around each intake and they would be open between units to permit cross-flow in front of existing trashrack structures. Closure panels would be installed on the upstream face and bottom of the individual shutters to form one monolithic structure across the front of each powerplant. A combination of steel cladding, closure panels, and gates would be provided to control the flow of water into the structure.

For the Left PP, four openings with hoist-operated, 50-foot-high by 50-foot-wide gates on the front of each shutter unit would allow selection of the reservoir withdrawal level. The upper shutter gates would act as a vertically adjustable weir between elevation 1290 and elevation 1240 to permit skimming of the reservoir surface water when the water level is above elevation 1270 assuming 30-foot minimum submergence. The middle shutter gates would control flow through openings from elevations 1180 to 1130, and the pressure relief gates would control flow through openings from elevations 1065 to 1015 directly upstream of the existing intake. The pressure relief gates would be equipped with 2-way pressure relief panels to prevent potential excessive differential pressures across the shutters caused by turbine startup or shutdown, or improper shutter operation. The low level gates would control flow through openings from elevation 985 to elevation 935 near the bottom of the reservoir forebay.

Right Powerplant gates would be similar to the Left Powerplant except that the low level gate openings for units 10, 11, and 12 would be located between elevations 895 and 845, and no low level gates would be provided for units 13 through 18. All gated openings would have trashracks to prevent debris accumulation inside the structure.

Installation of the shutter structures would probably be by the "stick building" method where the structures are built above their final position in the dry and then "jacked down" into their final position. This method was used to construct the Shasta Temperature Control Device. The proximity of the station service unit intakes to the intake for Unit 1 (Left Powerplant) would need to be addressed during future investigations.

The extreme underwater depths for construction would require saturation diving to install dam connections and attach the structures to the dam. As a result, installation of the shutters would require numerous unit outages for diver safety. The scope of the required outages would require further investigation and monetary losses due to required unit outages during construction were not included in the construction cost estimates for this initial review.

Preliminary cost estimates—

The basic layout of overall dimensions, major structural components, and construction factors were used to develop rough cost estimates for this review. Few calculations were performed to determine quantities associated with the Grand Coulee selective withdrawal structures. In most cases, quantities associated with the Shasta Temperature Control Device were factored to derive rough quantities. Costs were estimated based on calendar year 2003 unit prices and include an additional 20 percent for unlisted items and 25 percent contingencies to reflect the preliminary level of the estimates. Estimates of the underwater work requirements assume that the reservoir water surface will be at full elevation 1290 during construction. A breakdown of the factors and components applied in the preliminary cost estimates is included Appendix D.

Other considerations—

For comparison, the contract to install the Shasta Temperature Control Device was awarded for $63.7 million in November 1994. Although not investigated during this abbreviated study, it may be possible to significantly reduce the cost of providing selective withdrawal capabilities at the Left and Right Powerplants by installing selective withdrawal structures similar to those installed at Hungry Horse Dam in 1995. This type of selective withdrawal structure utilizes the existing trashrack structure in lieu of an external-framed structure to channel water into the existing penstocks. Semicircular gates traveling inside the existing trashrack structures would control the elevation of withdrawal. Although this concept would be less costly, it would not permit access to the cold water pool below the existing intakes.

Different selective withdrawal operational modes could be considered to help balance operational objectives using multi-level intakes at the Left and Right Powerplants either separately or in conjunction with the 3rd PP, and/or the Banks Lake pumping plant. For example, there may be some temperature benefit possible by changing daily operations, such as shifting from peaking operations to base power load or minimizing 3rd PP outflows during mid-day and increasing the 3rd PP flows later in the evening when the reservoir is not warming on the surface or in the river downstream. Moreover, the ability to achieve selective withdrawal objectives by fitting only one of the two powerplants with multilevel intakes would be much less costly and could also offer some operational advantages. These factors require additional, more detailed study. Simulation modeling could provide more accurate predictions of performance expectations and help define structural and operational criteria for use in further planning.

6.0 Optional Strategy 3 — Modifications at the Banks Lake pumping plant

Modifications to the Banks Lake pumping plant could also effectively modify water temperatures in the forebay and releases from Grand Coulee Dam. Potential benefits and costs of constructing selective withdrawal structures for the pumping plant were assessed in this review. Temperature implications of this strategy are complicated because of the operational functions of the pumping plant and number of variables associated with the Grand Coulee Dam operations and the annual hydrology and storage needs. Consequently, this review focused on the estimating costs for the selective withdrawal structural modifications and potential temperature effects were only briefly considered with respect to pumping rates and water volumes under existing operations.

Temperature Management Strategy

- Install multi-level intakes at the Banks Lake pumping station to allow selective withdrawal of surface water to enhance warm water removal and conserve cooler water for later release.
- Operate facilities to optimize withdrawal by tracking the seasonal drawdown to evacuate the warmer surface water from Lake Roosevelt during early summer warming period. Operate pumps primarily during mid-day hours to evacuate warmest water possible.
- Seasonal operational changes to fill Banks Lake as late in the spring or early summer to maximize warm water evacuation and reduce mixing effects.
- Evaluate return generation operations to minimize the return of warm water at times when downstream release temperatures are critical.

Option 3 Results

Potential temperature improvement benefits—

The potential temperature benefits of this strategy were only assessed qualitatively because of the complicated array of possible interactions between the Banks Lake pumping plant operations, the Grand Coulee Dam operations, and normal variations in hydrology and climate conditions from year to year. An average of 2.6 million acre-ft of water is pumped to Banks Lake annually and the pumping typically occurs from April to August, which coincides with the period of warming, stratification, and temperature management needs. This suggests that the Banks Lake facilities could be used to enhance warm water removal; however, predictive simulation capabilities are necessary to evaluate the conditions under specific operations. A modified 2-d model approach could be adapted to approximate conditions in the forebay area that may influence release water temperatures at Grand Coulee Dam.

Pre-appraisal estimated structural costs—

Total estimated costs to construct multi-level intake structures at the Banks Lake pumping plant including 20 percent unlisted items, 25 percent contingencies, and year 2003 unit prices:

- Multi-level intakes for 11 Banks Lake pump and pump-generation units: $84 million.

As an alternative, intake modifications could be installed only on the six pumping units without modifications to the pump-generation units. Again, these preliminary cost estimates only reflect capital construction costs, excluding any long-term operations and maintenance. Additional head loss factors and the feasibility of using the pumps to remove warm water without returning warm water at undesirable times of the year requires more detailed study.

Analysis and Discussion

Banks Lake pumping plant is an integral component of the Grand Coulee facilities that provides longer term water storage for the Columbia Basin Irrigation Project. It is a combined pumping and pump-generation facility that is designed to convey water to Banks Lake for annual storage and also can generate power by reversing flow and returning water to the Grand Coulee forebay area. Either operating function can affect water temperatures in the forebay area and associated releases to the Columbia River.

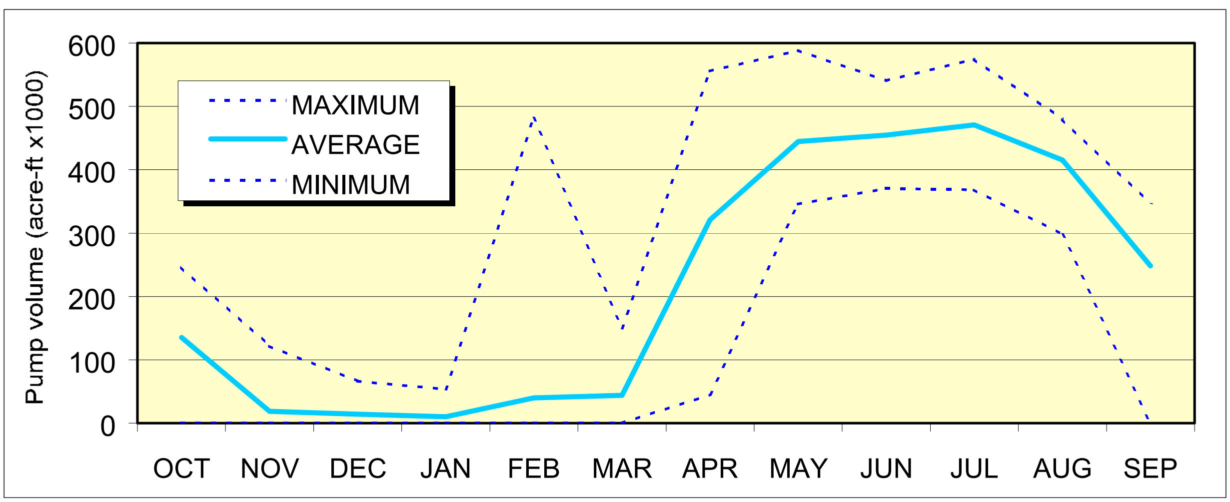


Figure 6-1. Average monthly pumping rates to Banks Lake from 1983 to 2002.

Monthly pumping rate volumes for the Banks Lake pumping plant from 1983 to 2002 are shown in Figure 6-1. The figure illustrates the typical annual pattern where the pumping to Banks Lake occurs from April to October. Total average annual volume was 2,607,000 acre-ft for this period with a maximum year of 2,961,000 acre-ft and a minimum of 2,112,000 acre-ft.

The average 2.6 million acre-ft of water pumped to Banks Lake each year is significant with respect to the maximum reservoir storage at Lake Roosevelt; however, it is a relatively small proportion of the of 79 million acre-ft per year average annual river flow. Pumping occurs in the summer during the maximum reservoir drawdown in June and seasonal temperature stratification from July to September (see Appendix A). Flow rates released from Grand Coulee also decrease beginning in August and are lowest in September. Furthermore, it is difficult to determine how the Banks Lake pumping volumes compare to the actual volumes of warmer water layers in the forebay or how upstream conditions might change with modified pumping. The combination of variables is complex and will likely require 2-d or adapted 3-d simulation modeling to evaluate characteristics of the system forebay area and related conditions in the upper reservoir.

Pumping plant intake cost factors—

The Banks Lake pump plant has a total of 6 pumping units (P) and 6 pump-generating (PG) units that can be operated in both directions. Multi-level intake structures designed for Shasta Dam in 1997 were used to obtain rough size estimates to enclose 11 of the 12 intakes of the Banks Lake plant (PG12 is constricted by high topography and rock outcropping). The estimate assumes that steel truss shutter structures would be attached to the upstream face of the units. Individual steel structures would be built around the intakes for pumping units P1, P3, P5, and pump-generating units PG7, PG9, and PG11. After these structures are attached, structural members, cladding, gates, and trashracks, would be installed between each pair in front of the intakes for pumping units P2, P4, P6, and pump-generating units PG8 and PG10.

Each shutter structure would be approximately 45 feet wide (cross canyon direction), 45 feet deep (stream direction) and 140 feet high. Each structure would be suspended from a rigid frame (knee-braced support) attached to the dam at centerline elevation 1305. A hoist deck would be provided at the top of each structure at elevation 1310. The shutters would be open between units to permit cross-flow in front of the existing trashrack structures and closure panels would be installed on the upstream face and bottom of the shutters to form one monolithic structure in front of the pumping plant. A combination of steel cladding, closure panels, and gates would be provided to control the flow of water into the structure.

The shutter structures would be operated to evacuate the warmer surface water from the forebay into Banks Lake. Two hoist-operated, 40-foot-wide gates on the front of each shutter unit would be provided to allow selection of the reservoir withdrawal level. Upper shutter gates would act as a vertically adjustable weir between elevations 1290 and 1250 to permit skimming of surface water when the reservoir is above elevation 1270, allowing for a 20-foot minimum submergence. Pressure relief gates would control flow through the openings from elevation 1210 to elevation 1175 directly upstream of the existing intakes. The pressure relief gates would be equipped with 2-way pressure relief panels to prevent the potential for excessive differential pressure across the shutters caused by turbine startup, shutdown, or improper shutter operation. All gated openings would have trashracks to prevent debris accumulation inside the structure. Sketches showing the general layout of shutter structures are included in Appendix D.

Installation of the Banks Lake shutter structures would probably be by the "float and sink" method where the structures are built on a barge in the reservoir and lowered into position by controlled-sinking methods. This method was used to construct selective withdrawal structures at Flaming Gorge Dam in Wyoming. Saturation diving would probably be utilized to install dam connections and attach the structures to the dam. Installation of the shutters would require a number of unit outages for diver safety. The magnitude of these outages is indeterminate and monetary losses due to required unit outages during construction have not been included in the construction cost estimates.

Preliminary cost estimates—

The appraisal level field cost estimate for installing selective withdrawal structures around the intakes at the Banks Lake pumping plant is $84 million. This estimate is based on calendar year 2003 unit prices, including 20 percent unlisted items and 25 percent contingencies. The estimate assumes the reservoir water surface during construction will be at elevation 1290 for purposes of underwater work requirements. A detailed breakdown of these costs is included in Appendix D.

7.0 Future Planning Considerations

In reviewing these three optional strategies, a number of different operating schemes, methods to implement the option, or combined approaches are evident. These factors may be important to consider in further development of an option or in the overall direction taken in the future TMDL planning discussions. Operating schemes are a good example because for each strategy, several operational management sub-options were apparent. The major review findings and additional considerations for each strategy are briefly summarized in the following paragraphs.

Option 1 Considerations

- Operational changes to the existing facility operations could be done independently, or in conjunction with Banks Lake pumping plant modifications.
- Costs associated with this option are linked to generation efficiency and maintenance factors that depend on the specific details of the operating scenario applied.
- Cursory review of operations data indicates the three powerplants are almost always used in some combination, which suggests the impacts of shifting operations toward one unit or another is difficult to assess from the available historic data.
- Estimates of temperature conditions could be refined using hourly operations data rather than daily averages used in this simplified analysis.
- The vertical range of influence that exclusive operations of one powerplant may have on localized stratification in the forebay area is unknown.
- Potential effects of operations on internal reservoir currents (and interflows) are important factors that could influence the timing of annual temperature conditions and operational criteria developed to balance release temperatures with internal reservoir objectives.
- Significant operational changes could alter reservoir thermal stratification patterns and/or seasonal characteristics that cannot be evaluated directly from historic data.
- The potential benefits and resource implications could be more accurately assessed using hydrodynamic reservoir modeling and in-situ testing under defined conditions.

Option 2 Considerations

- Costs of these huge structural components are expensive, although the costs include contingency factors to reflect the rough preliminary level of estimates.
- Costs could be reduced if only implemented on the left powerplant; however, the costs are still relatively high and effectiveness of this approach is uncertain.
- More efficient and effective temperature management is expected because the multi-level intakes allow selective access to water at the full range of reservoir water depths.

- Performance expectations could be evaluated more accurately using simulation modeling and more detailed information concerning the multi-level intake structures.
- Selective withdrawal outlet structures have proven effective for temperature regulation at numerous sites and different operating conditions, although this situation is complicated because of the large scale and compound configuration of the existing facilities.
- A number of alternative operating strategies for using these facilities to access warmer or cooler water may require study to determine the optimal management strategy and refine conceptual details for any further design development stages.
- This type of structural modification is also expected to provide greater flexibility to make adjustments to balance downstream and in-reservoir operating objectives.

Option 3 Considerations

- Temperature management using the Banks Lake pumping station should be coordinated with Grand Coulee Dam to develop an integrated operational plan.
- The costs of the multi-level intakes are relatively high and the potential benefits derived from enhancing the evacuation of warmer surface water are uncertain.
- Other related strategies include the ability to install selective intake structures for only the six pumping units (no changes to the six pump-generator units)
- Management of temperature conditions in water returned to the Grand Coulee forebay area during pump-generator operations requires further investigation.
- Hydrodynamic modeling could also help evaluate this strategy or related options because of the complicated configuration of the pumping plant facilities and forebay area.
- The ability to modify the Banks Lake pumping operations without structural changes or to modify late season pumping operations to increase the transport of upstream inflows of cooler water may warrant additional investigation.

Additional Information Needs

The analysis for this initial review was based on certain assumptions. In many instances, it is apparent that additional information or predictive simulation capabilities are necessary to help understand conditions or improve the accuracy of estimates. In recent years, Reclamation has completed several efforts to evaluate available information and work toward compiling data to address temperature, dissolved gas and other relevant issues. For example, three new climate stations were installed on-site, and additional temperature profile monitoring was initiated at Lake Roosevelt as described in a data assessment (Reclamation, 2002). An analysis of reservoir bathymetry data was completed recently (Reclamation, 2003) that could ultimately support the development of a 2-d hydrodynamic reservoir model that could be used to evaluate temperature conditions, operational alternatives, or other conditions in the reservoir.

Lake Roosevelt is a dynamic reservoir that is subject to many variables attributed to the prevalent hydrology and climate characteristics of the Columbia Basin and complex operating conditions associated with Grand Coulee Dam. Simulation modeling could be useful to examine different attributes of the existing facilities and established operating criteria, or to evaluate the potential implications of alternative management strategies developed in the future.

Hydrodynamic reservoir temperature modeling capabilities—

The potential uses and need for simulation modeling was evident for all three options addressed in this initial review. This points out the types of issues that could be explored with appropriate reservoir modeling capabilities. Predictive simulation is really the only means to examine issues that are not represented by the range of historic data, and is also advantageous to gain insight into critical process factors before expending additional resources. The hydrodynamic configuration and operational variables imposed by Grand Coulee Dam can affect conditions in the reservoir and downstream river drastically. In addition, although Lake Roosevelt has a rapid flow through rate that could simplify certain processes and help compensate for modeling error, it also has some confounding properties attributed to physical and hydrologic conditions and the effects of reservoir drawdown, seasonal changes, and daily power operations. The current state of the art in 2-d fully hydrodynamic modeling can accommodate many of these conditions and accurately simulate conditions in many reservoirs. Consequently, it appears there is reasonable potential to use a 2-d model to examine conditions at Grand Coulee Dam and Lake Roosevelt.

Changes in the upstream (inflow) and downstream (release) temperature data indicate the actual reservoir flow-through time can shift significantly over the course of an annual cycle. This could indicate the presence of interflow slipstreaming currents in the reservoir and effect the direction taken in any management alternatives. Perhaps more importantly, although recent studies have indicated that both 1-d and 2-d models can produce similar results based on historic temperature data for Lake Roosevelt (Yearsley, 2003), it also suggests that a 2-d fully hydrodynamic model approach is essential to evaluate alternatives that could potentially alter the strength or timing of vertical gradients or spatial temperature patterns in the reservoir.

In-situ temperature monitoring at each existing powerplant—

Additional temperature data collected at each of the three Grand Coulee powerplants could help to provide a better understanding of operational schemes, discharge, and release temperatures for the Left, Right, and 3rd powerplants under existing conditions. In-situ temperature monitoring would also contribute additional data to support future simulation modeling. In addition, the hydraulic conditions in the approach channel and withdrawal characteristics of the 3rd powerplant may require further study to accurately model release temperatures. This may require adaptation of 2-d modeling to represent the three-dimensional configuration of the Grand Coulee forebay and field studies to collect more detailed data for the 3rd powerplant intakes.

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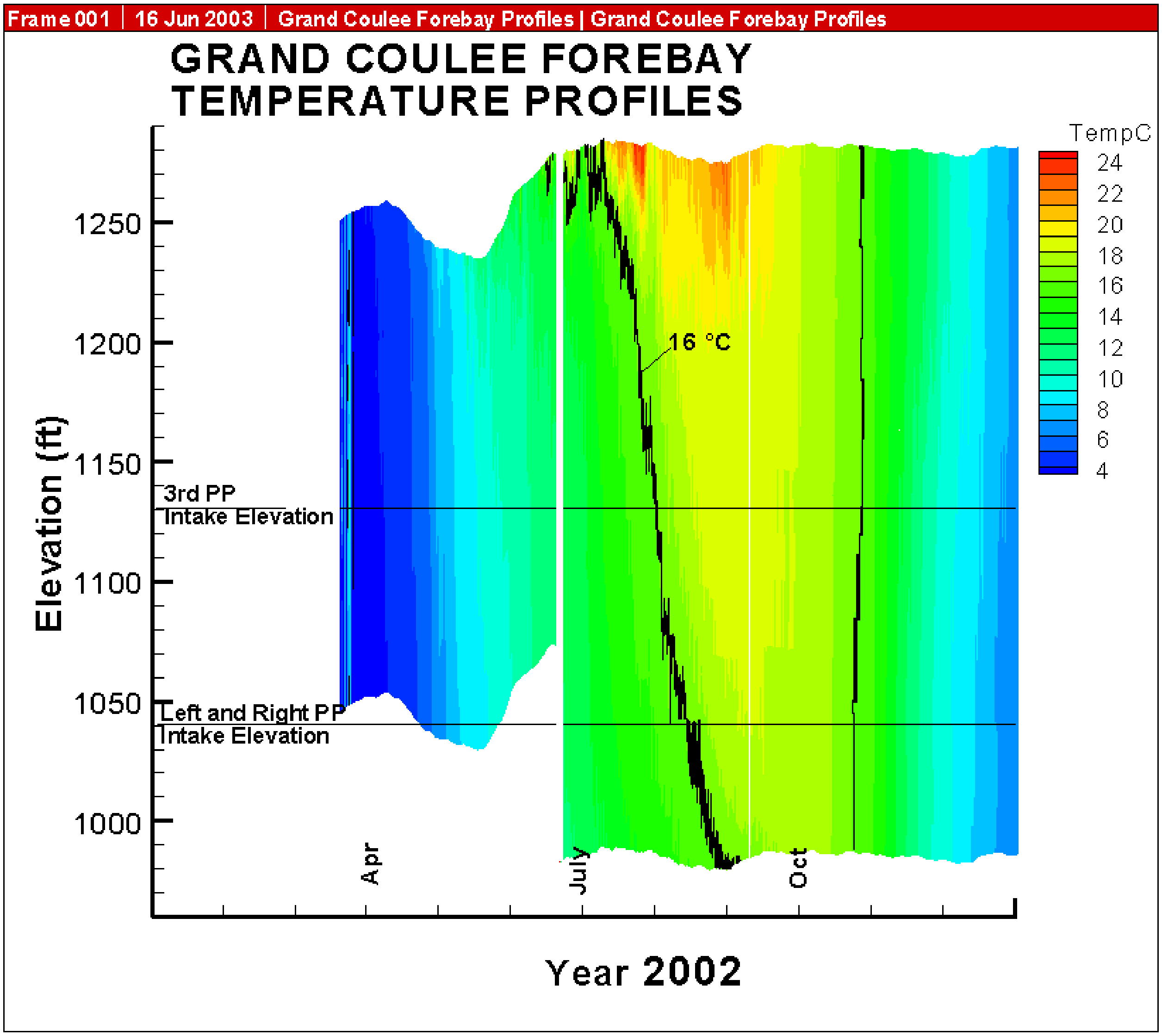
Appendix A

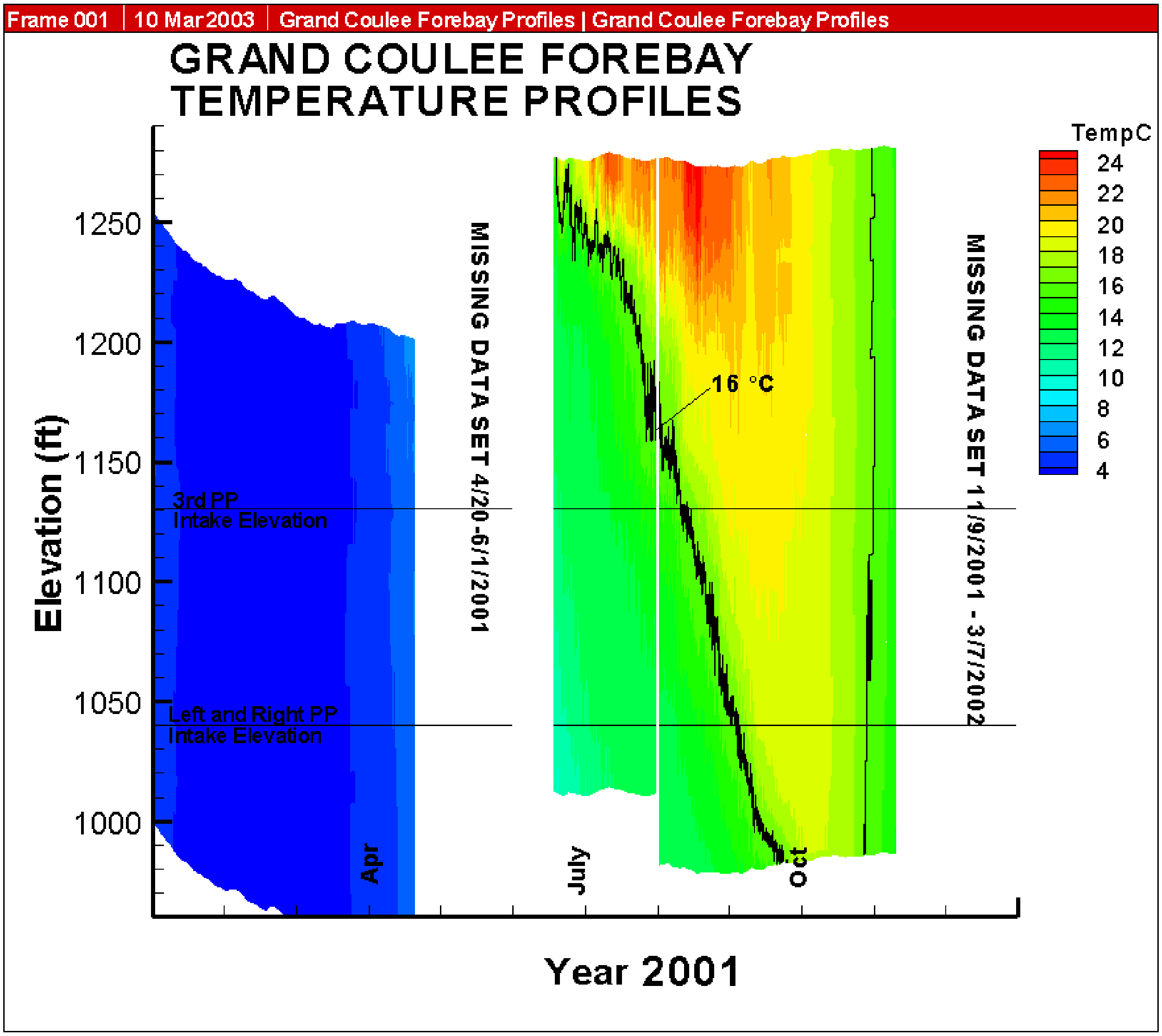
Vertical profile plots showing temperature stratification in the forebay area of Grand Coulee Dam

- *Vertical temperature profiles in Grand Coulee forebay for 2002*
- *Vertical temperature profiles in Grand Coulee forebay for 2001*
- *Vertical temperature profiles in Grand Coulee forebay for 2000*
- *Vertical temperature profiles in Grand Coulee forebay for 1999*
- *Vertical temperature profiles in Grand Coulee forebay for 1998*

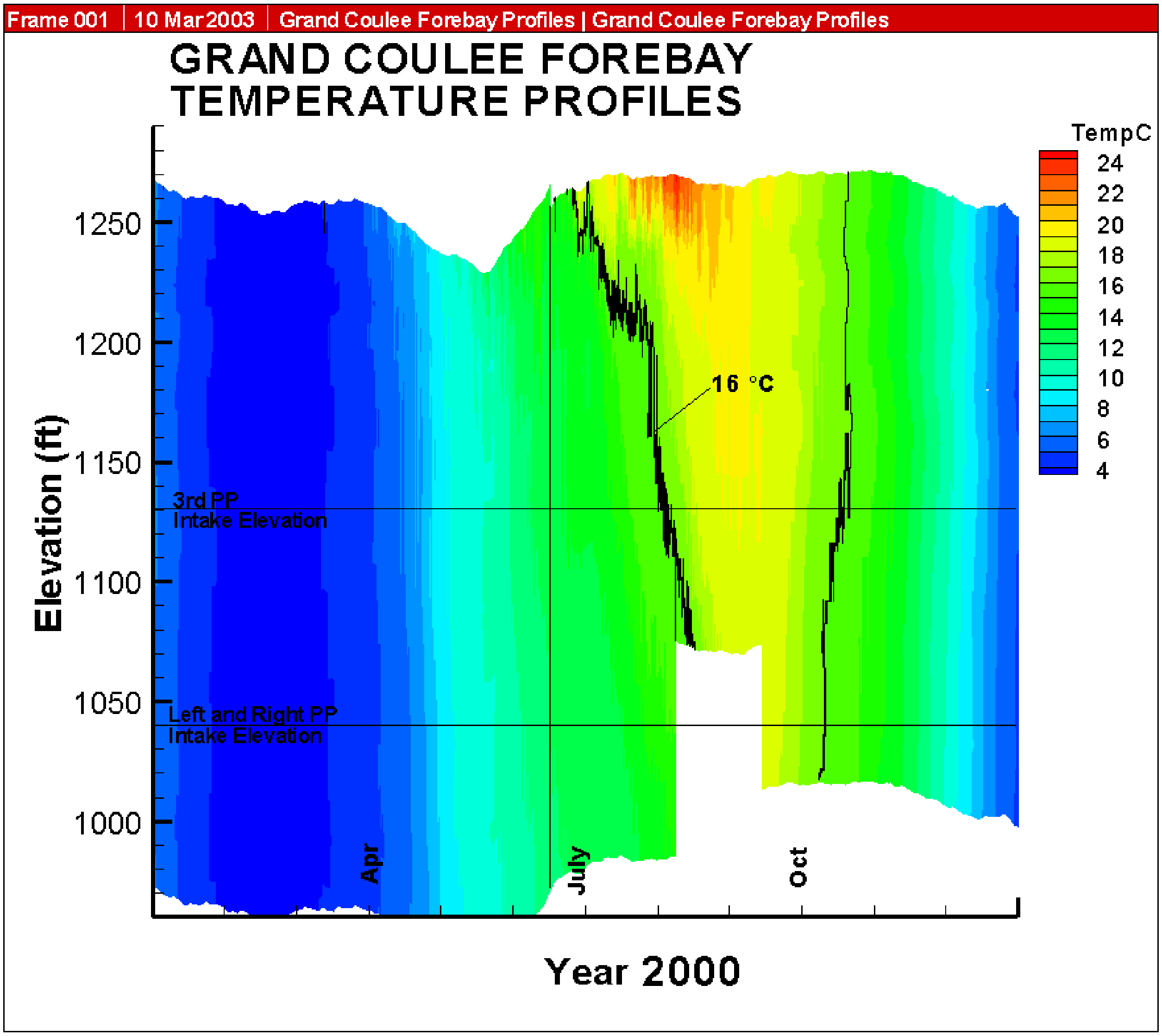
Note: Continuous data collected by Reclamation at 15-minute intervals using thermistor string located at Grand Coulee forebay site.



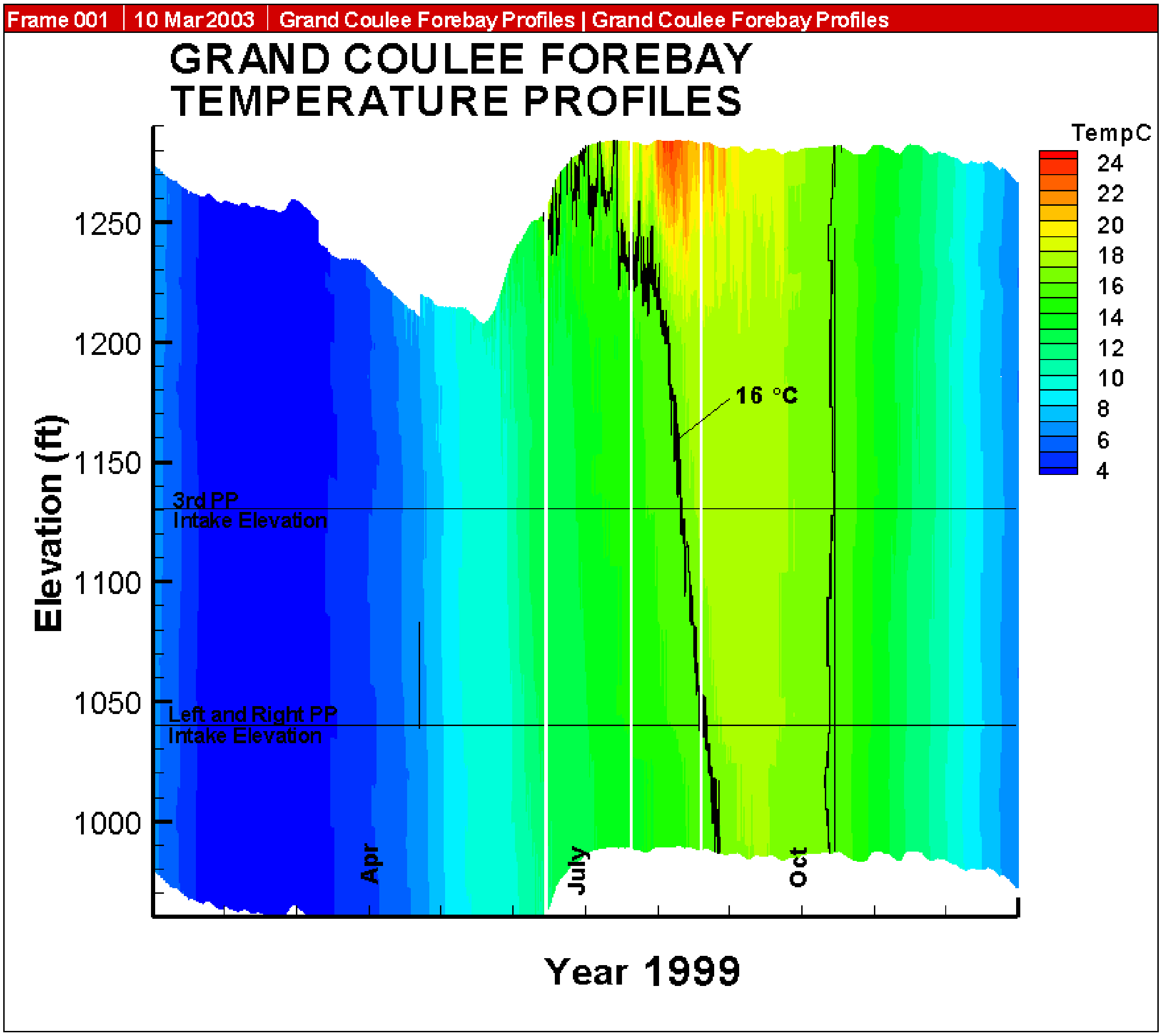
Vertical temperature profiles in Grand Coulee forebay for 2002



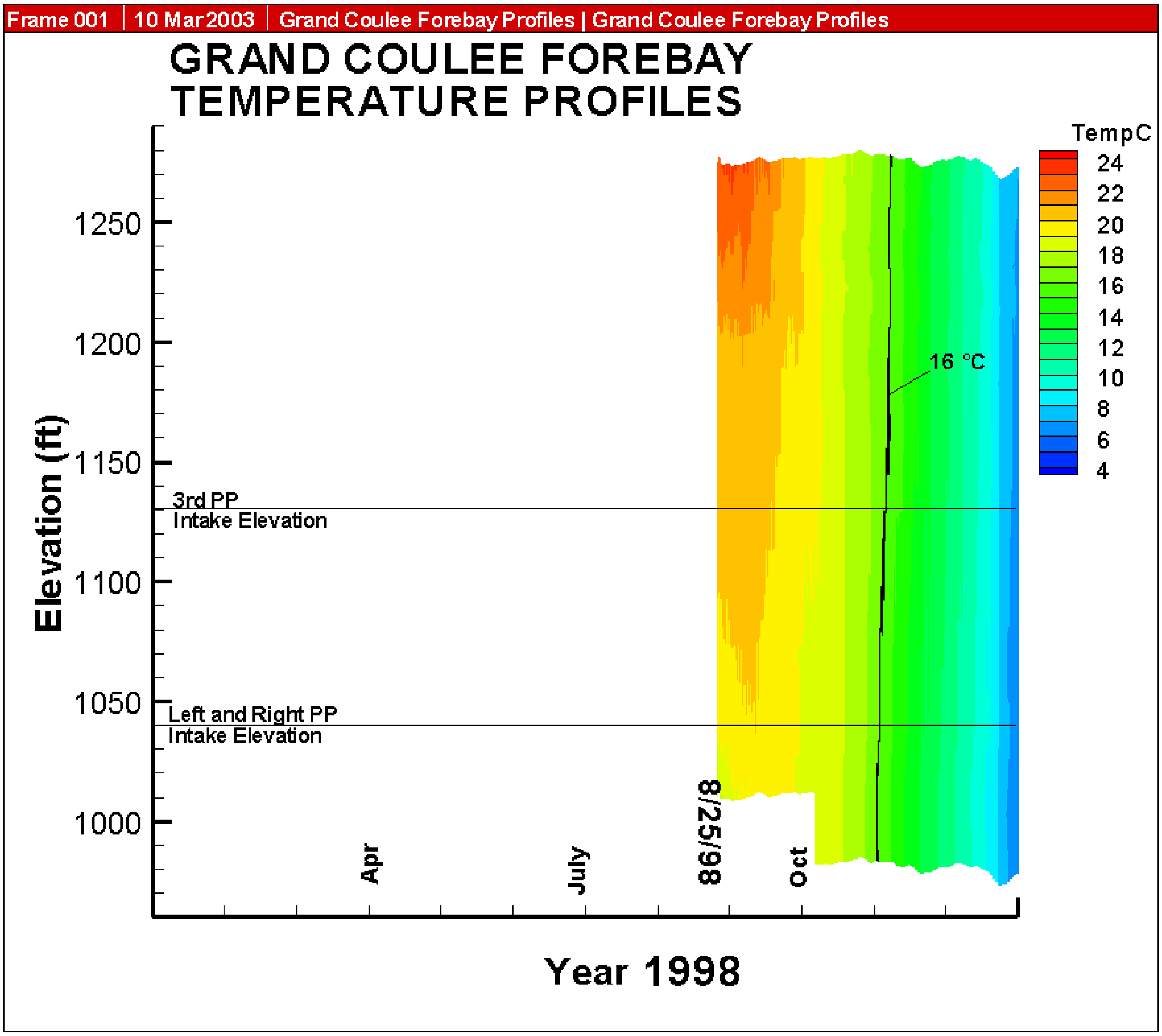
Vertical temperature profiles in Grand Coulee forebay for 2001



Vertical temperature profiles in Grand Coulee forebay for 2000



Vertical temperature profiles in Grand Coulee forebay for 1999



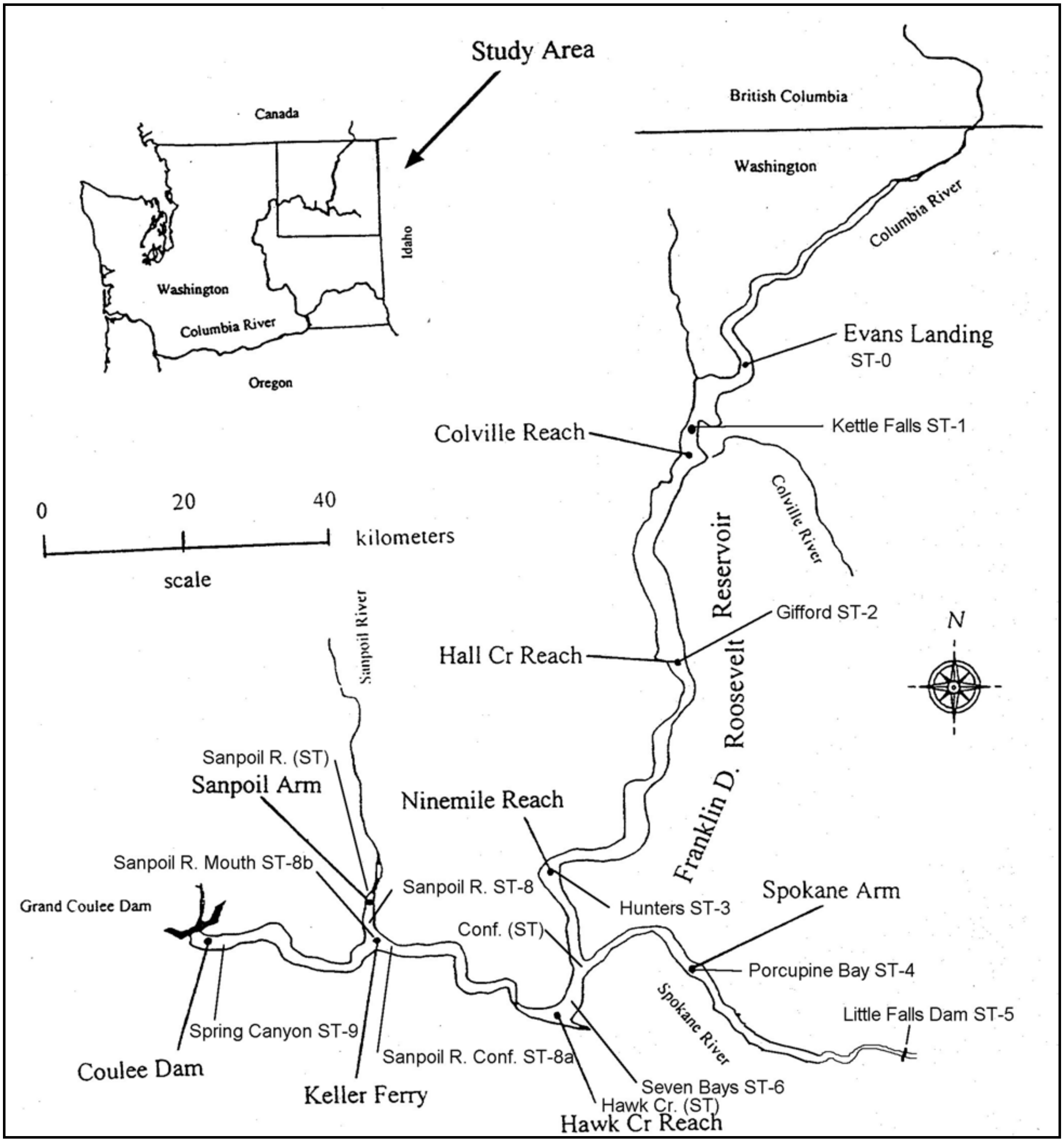
Vertical temperature profiles in Grand Coulee forebay for 1998

Appendix B

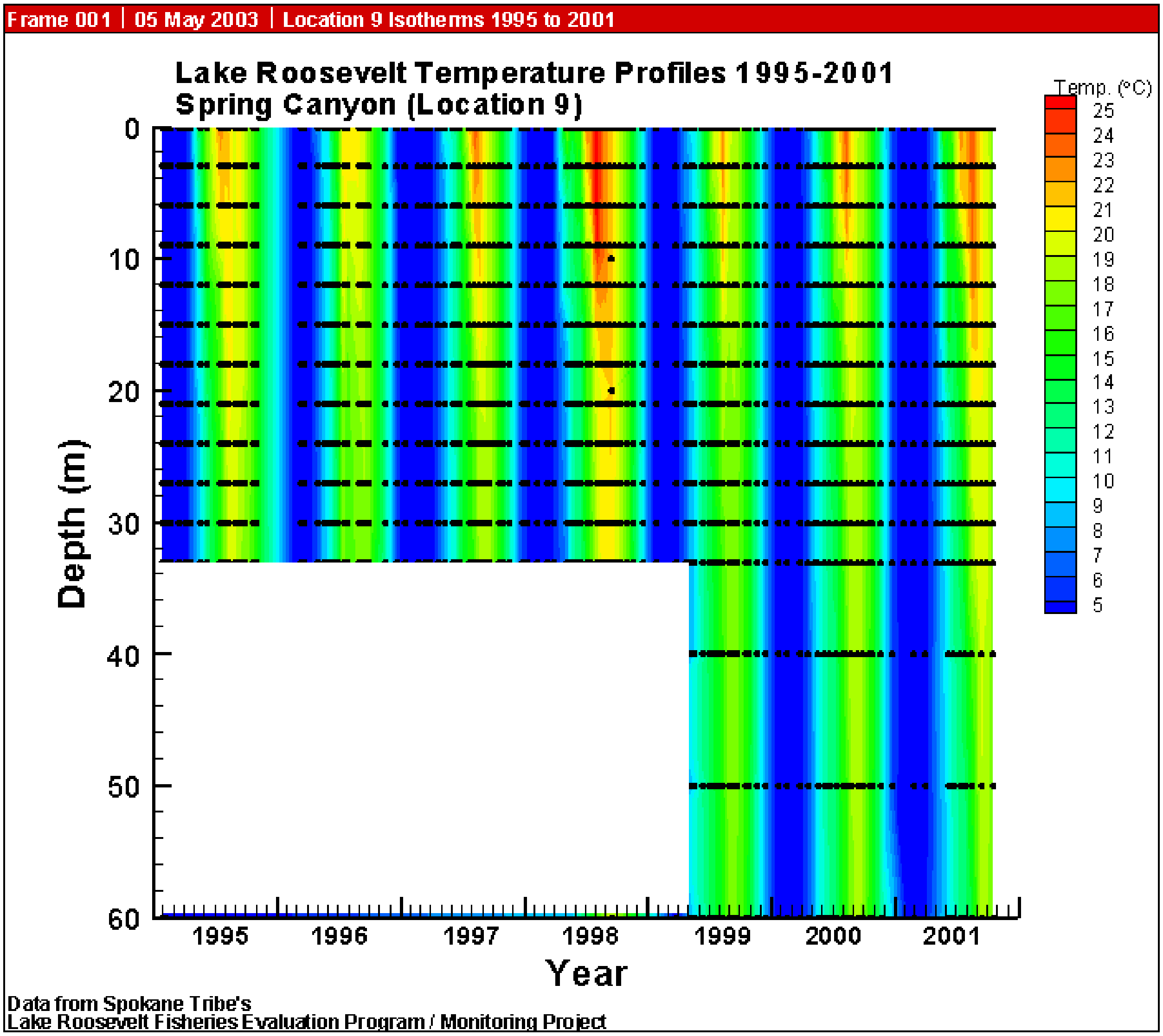
Vertical profile plots showing stratification variations by year and location in Lake Roosevelt

- *Locations for vertical profile data collected by Spokane Tribe of Indians*
- *Temperature profiles for 1995 to 2001, Spring Canyon, Site ST-9*
- *Temperature profiles for 1998 - 2001, Spring Canyon, Site ST-9*
- *Temperature profiles for 1998 - 2001, Spokane River, Site ST-4*
- *Temperature profiles for 1998 - 2001, Hunters, Site ST-3*
- *Temperature profiles for 1998 - 2001, Gifford, Site ST-2*
- *Temperature profiles for 1998 - 2001, Kettle Falls, Site ST-1*
- *Temperature profile for water year 2000, Spokane River, Site ST-4*
- *Temperature profile for water year 2000, Hunters, Site ST-3*
- *Temperature profile for water year 2000, Gifford, Site ST-2*
- *Temperature profile for water year 2000, Kettle Falls, Site ST-1*

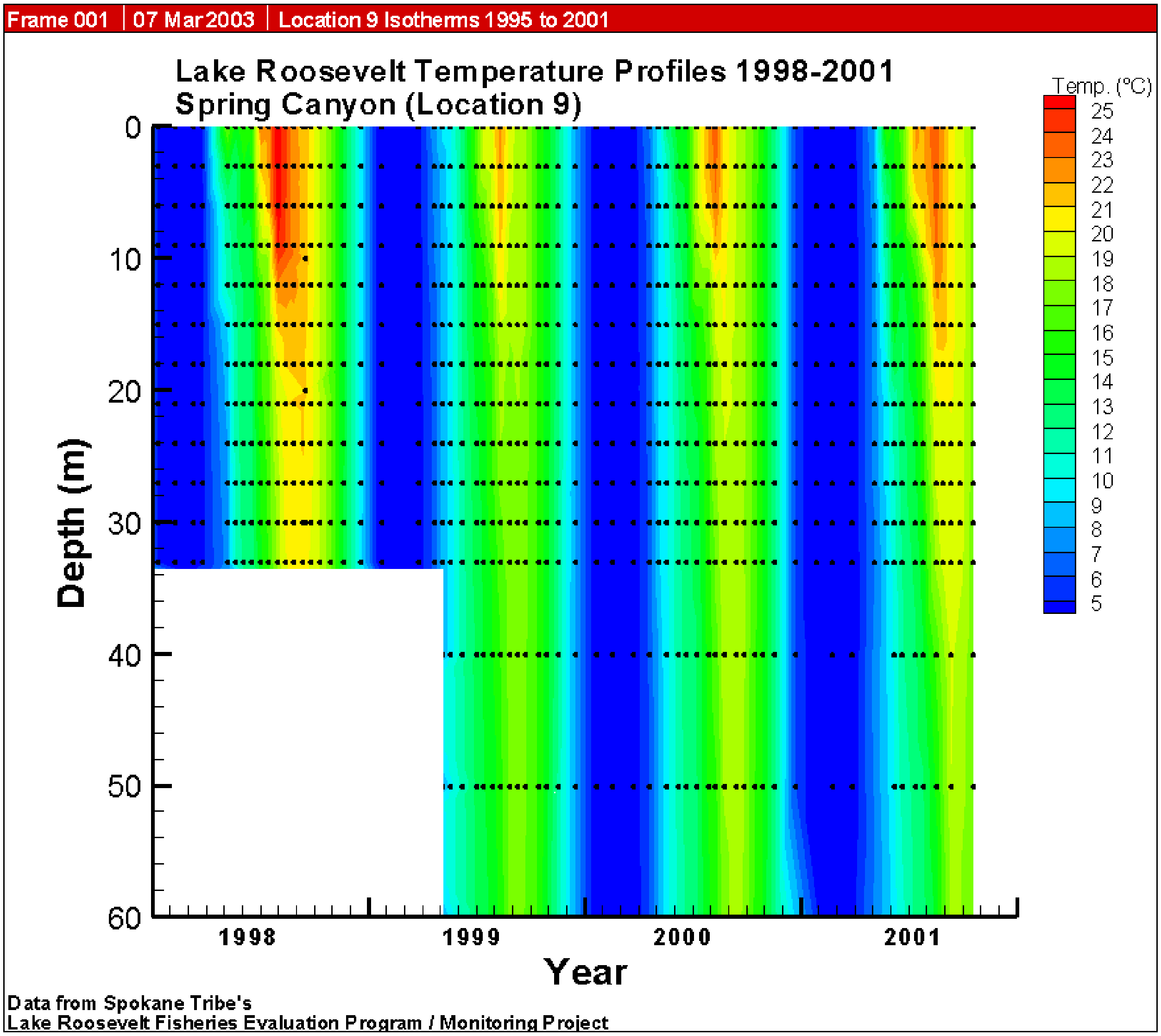
Note: Vertical temperature profile data collected by the Spokane Tribe of Indians staff at locations and depths indicated within Lake Roosevelt.



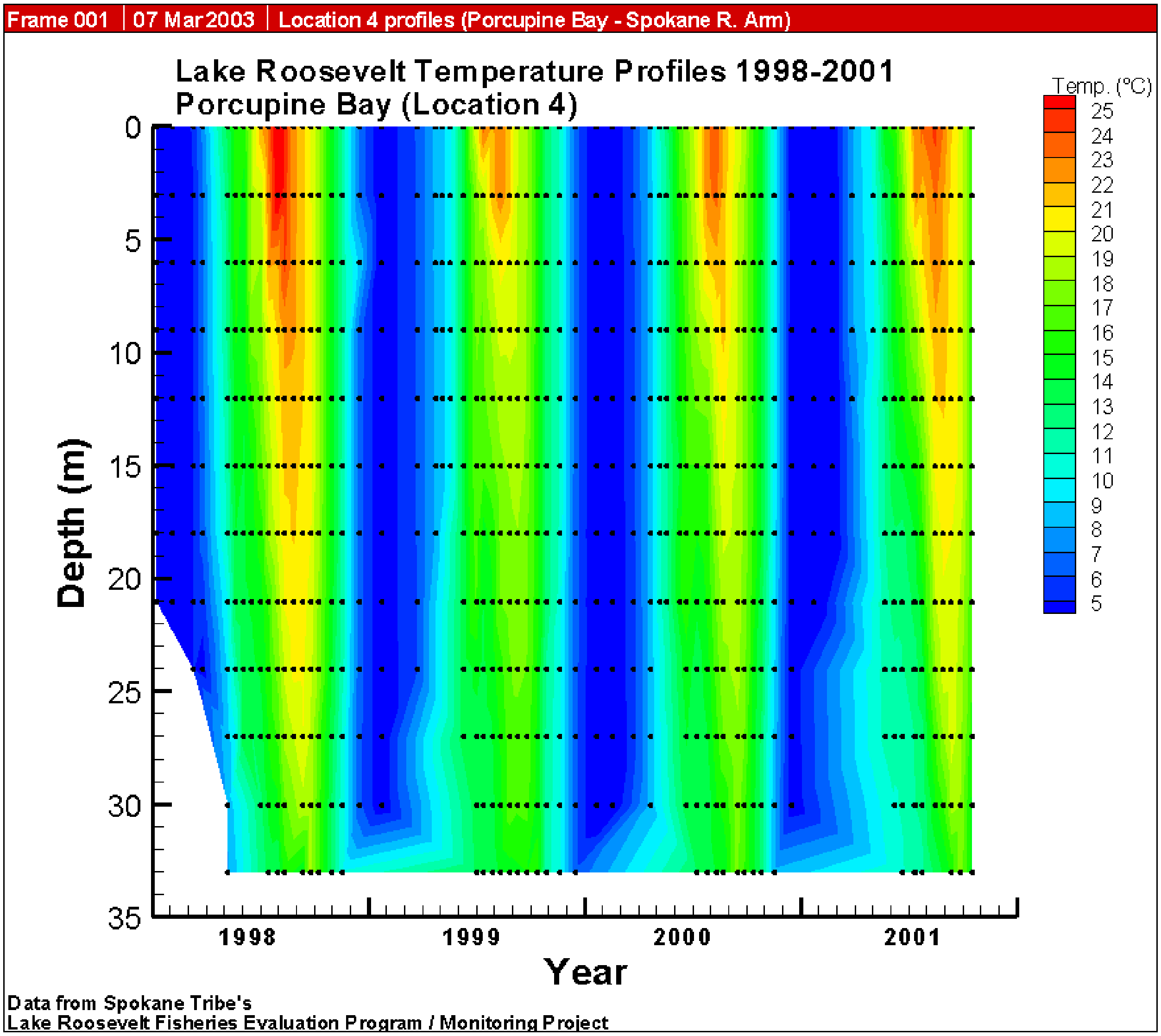
Locations for vertical profile data collected by Spokane Tribe of Indians



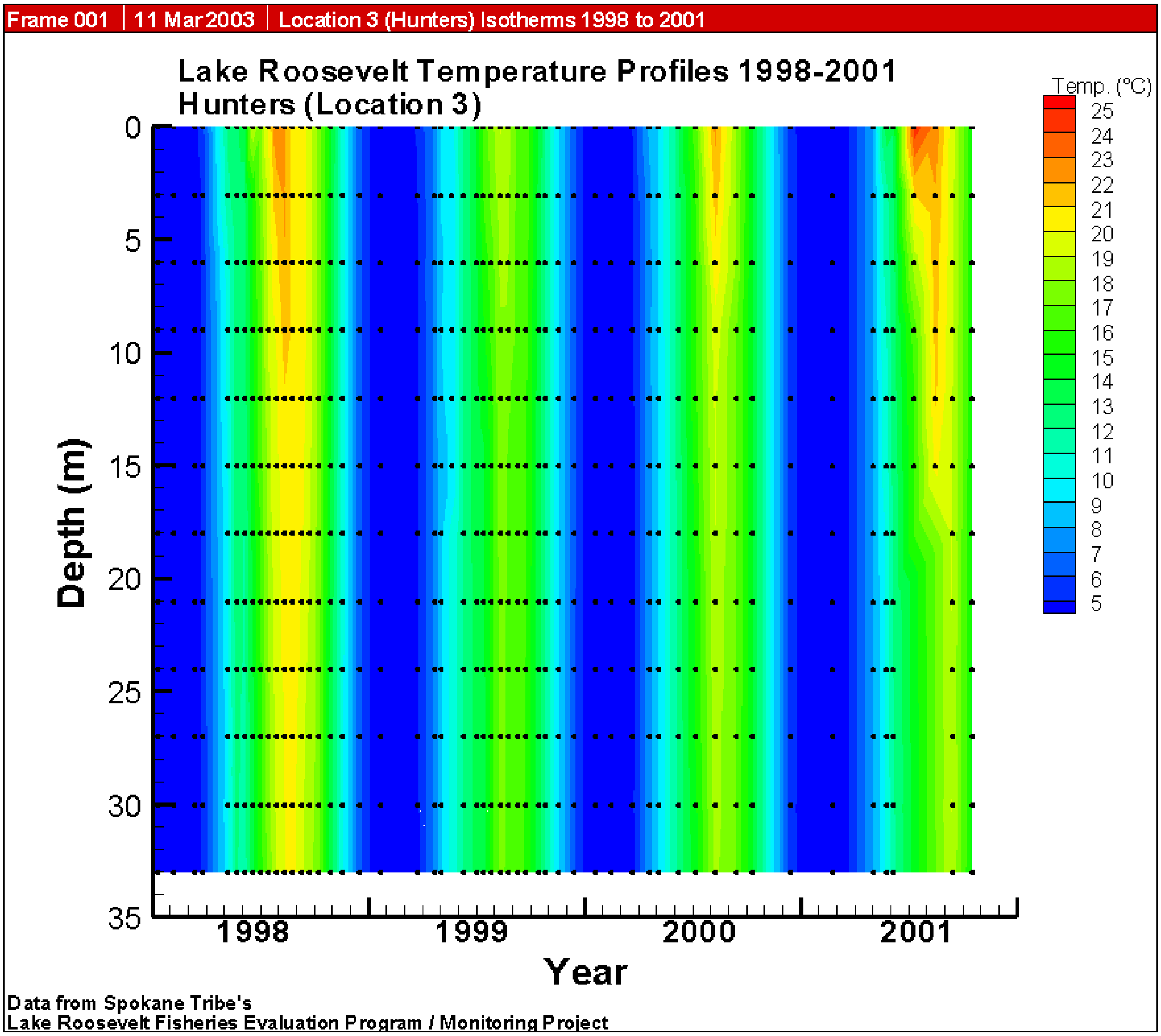
Temperature profiles for 1995 to 2001, Spring Canyon, Site ST-9



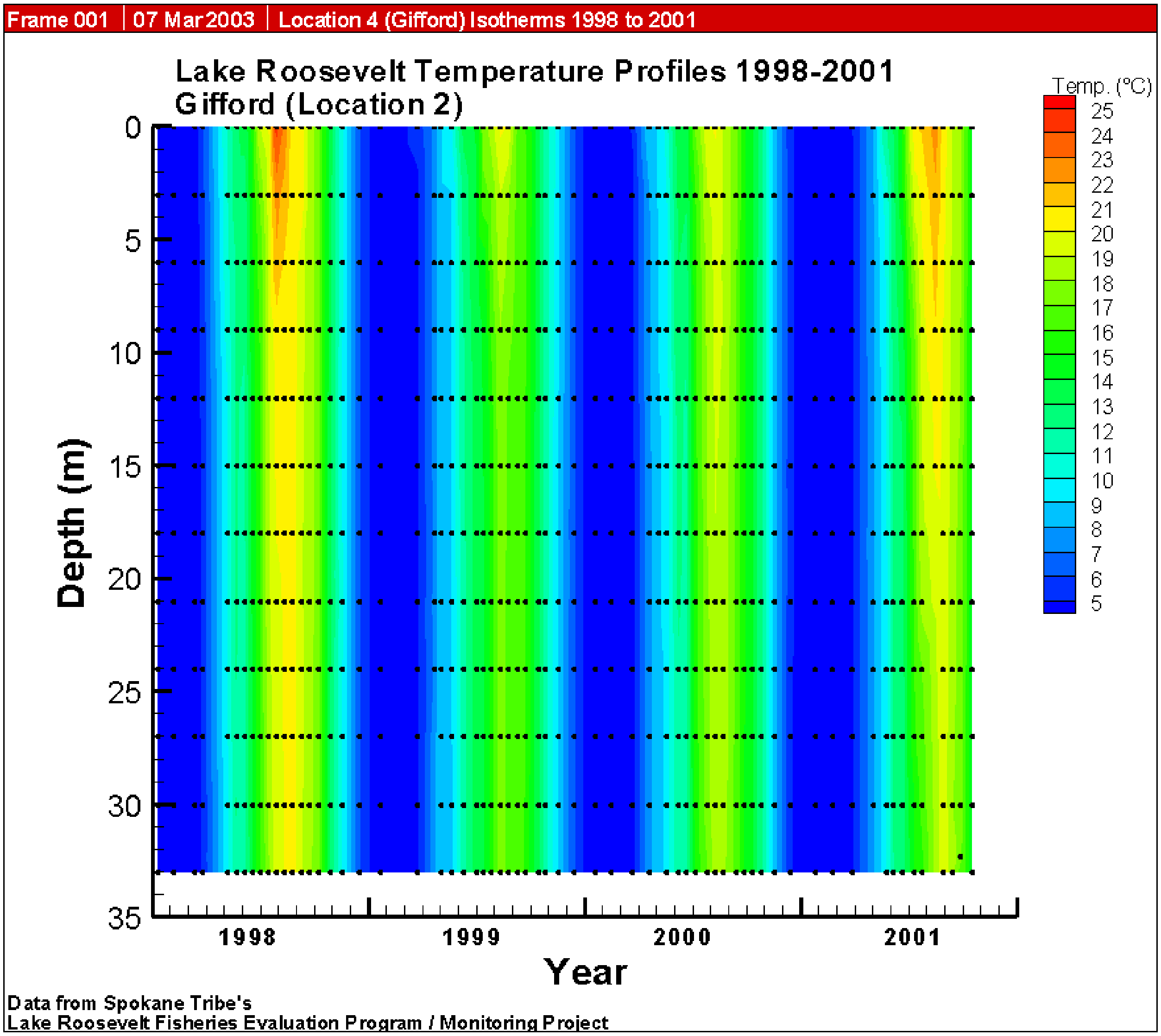
Temperature profiles for 1998 - 2001, Spring Canyon, Site ST-9



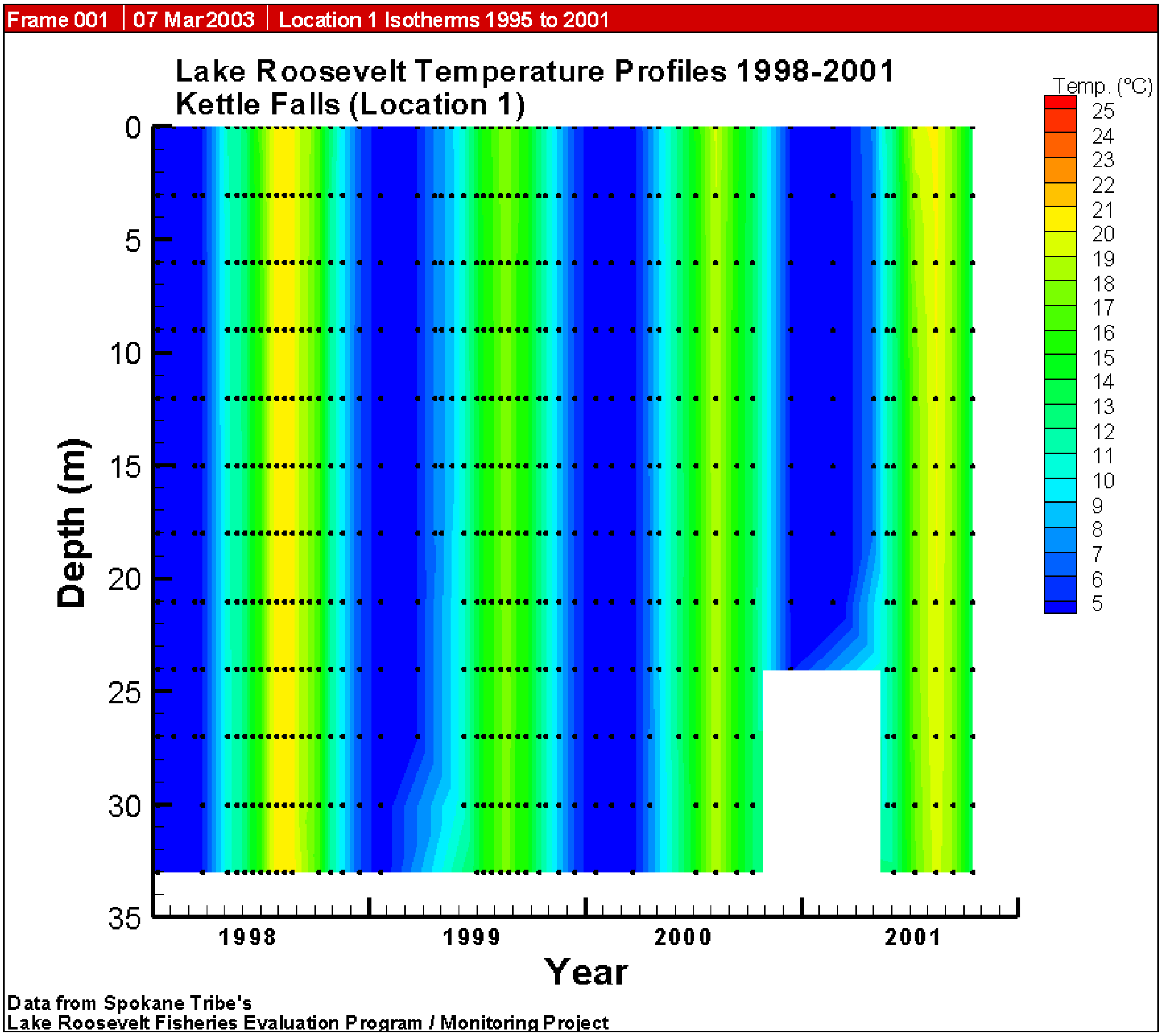
Temperature profiles for 1998 - 2001, Spokane River, Site ST-4



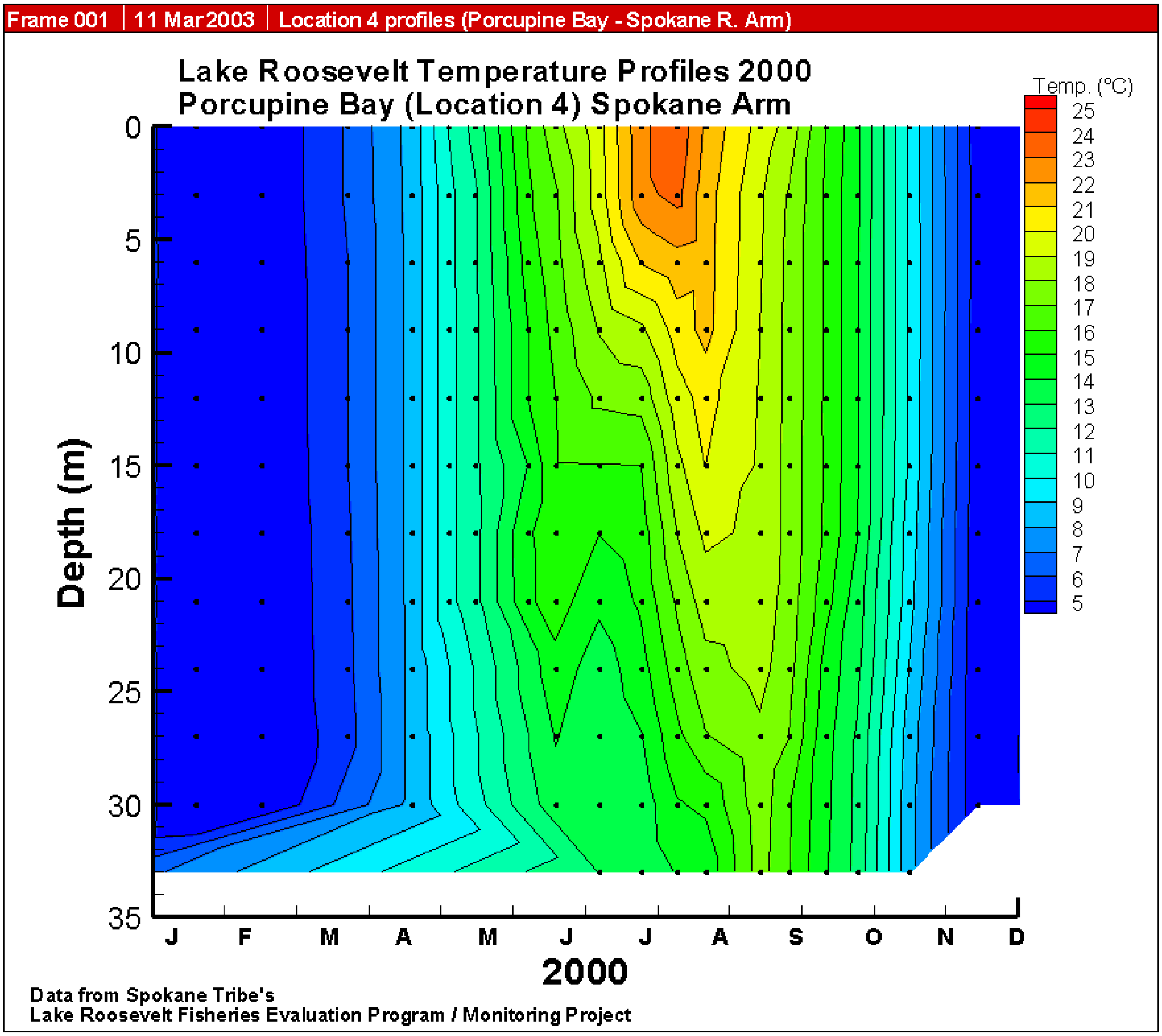
Temperature profiles for 1998 - 2001, Hunters, Site ST-3



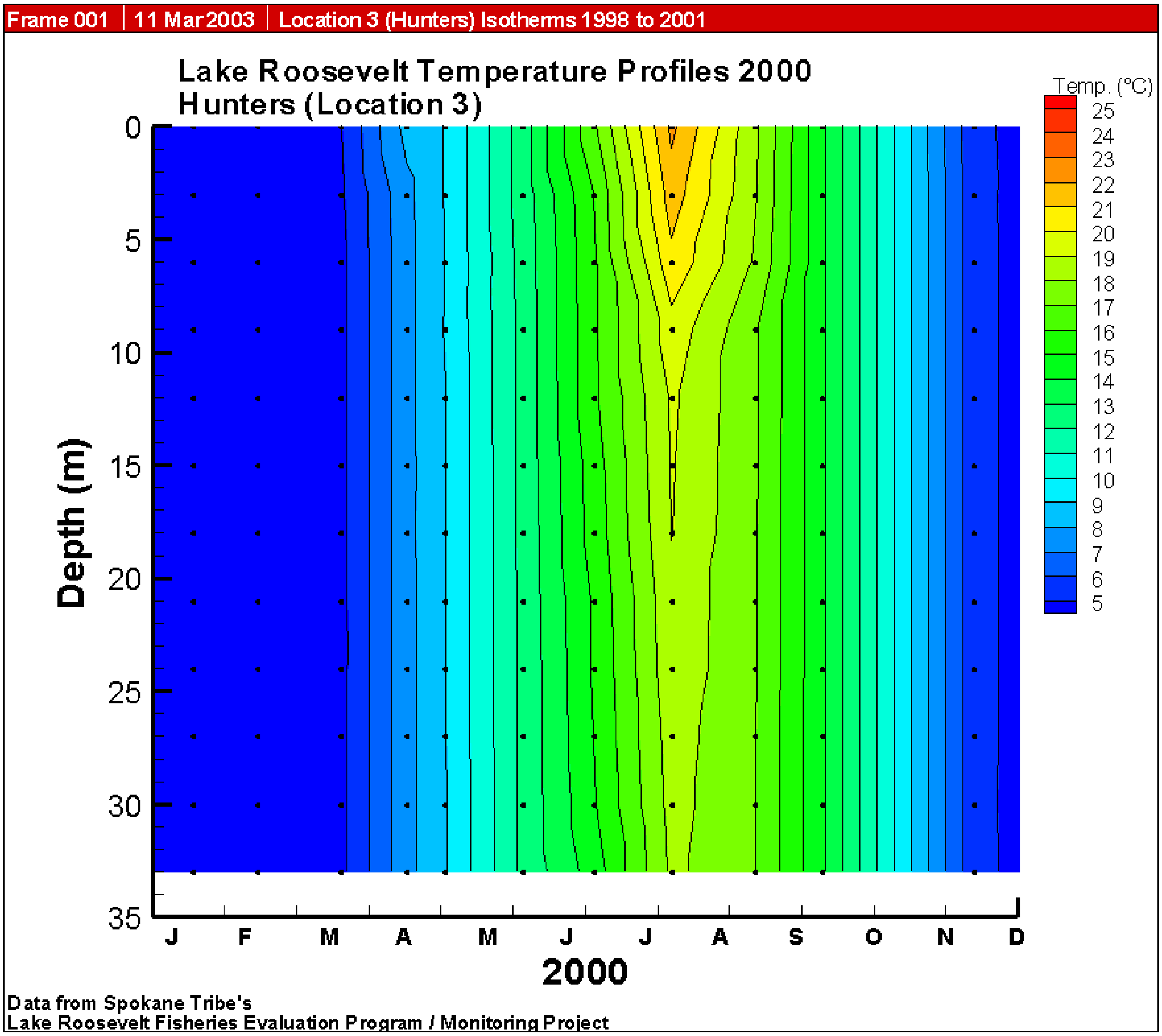
Temperature profiles for 1998 - 2001, Gifford, Site ST-2



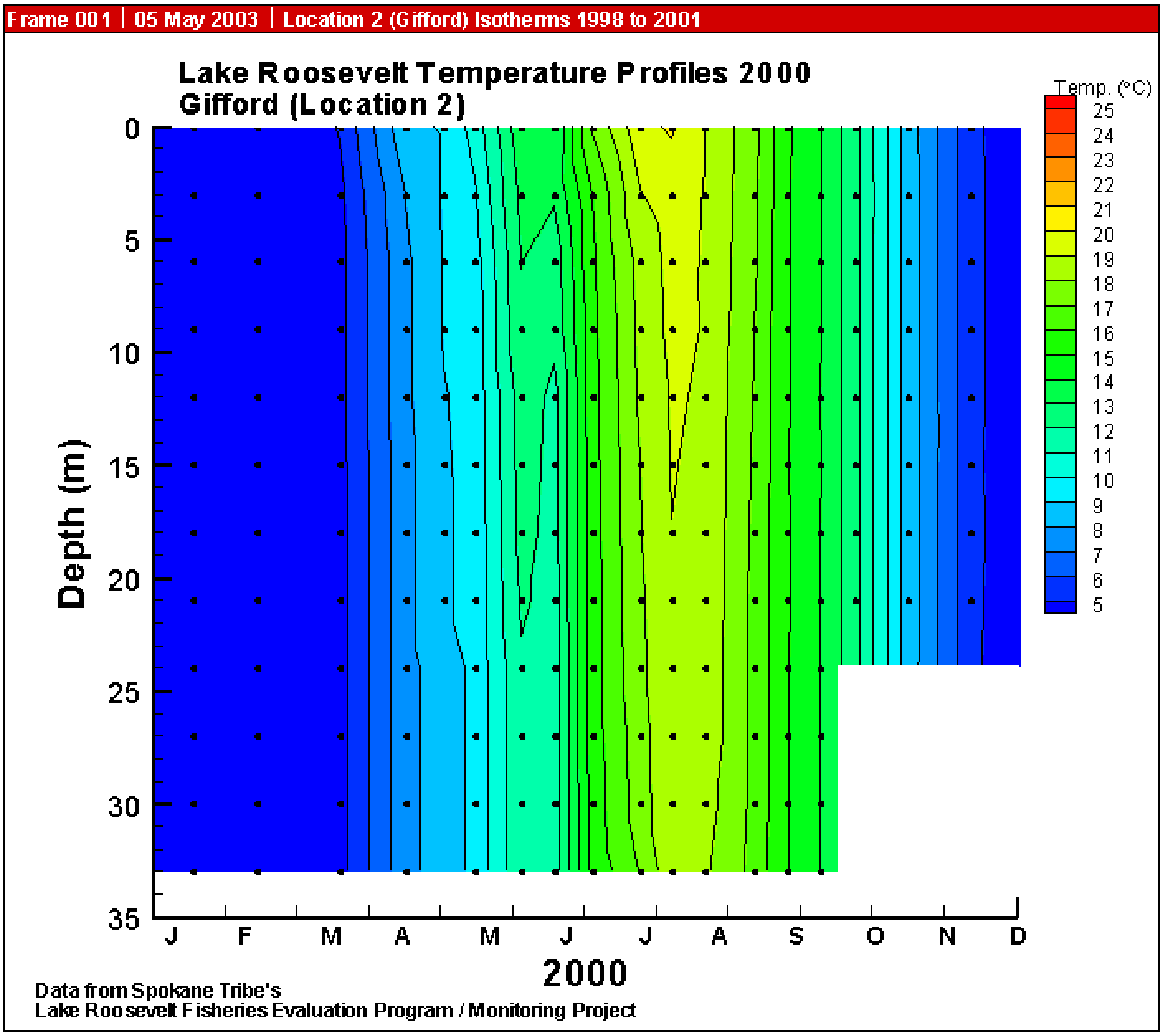
Temperature profiles for 1998 - 2001, Kettle Falls, Site ST-1



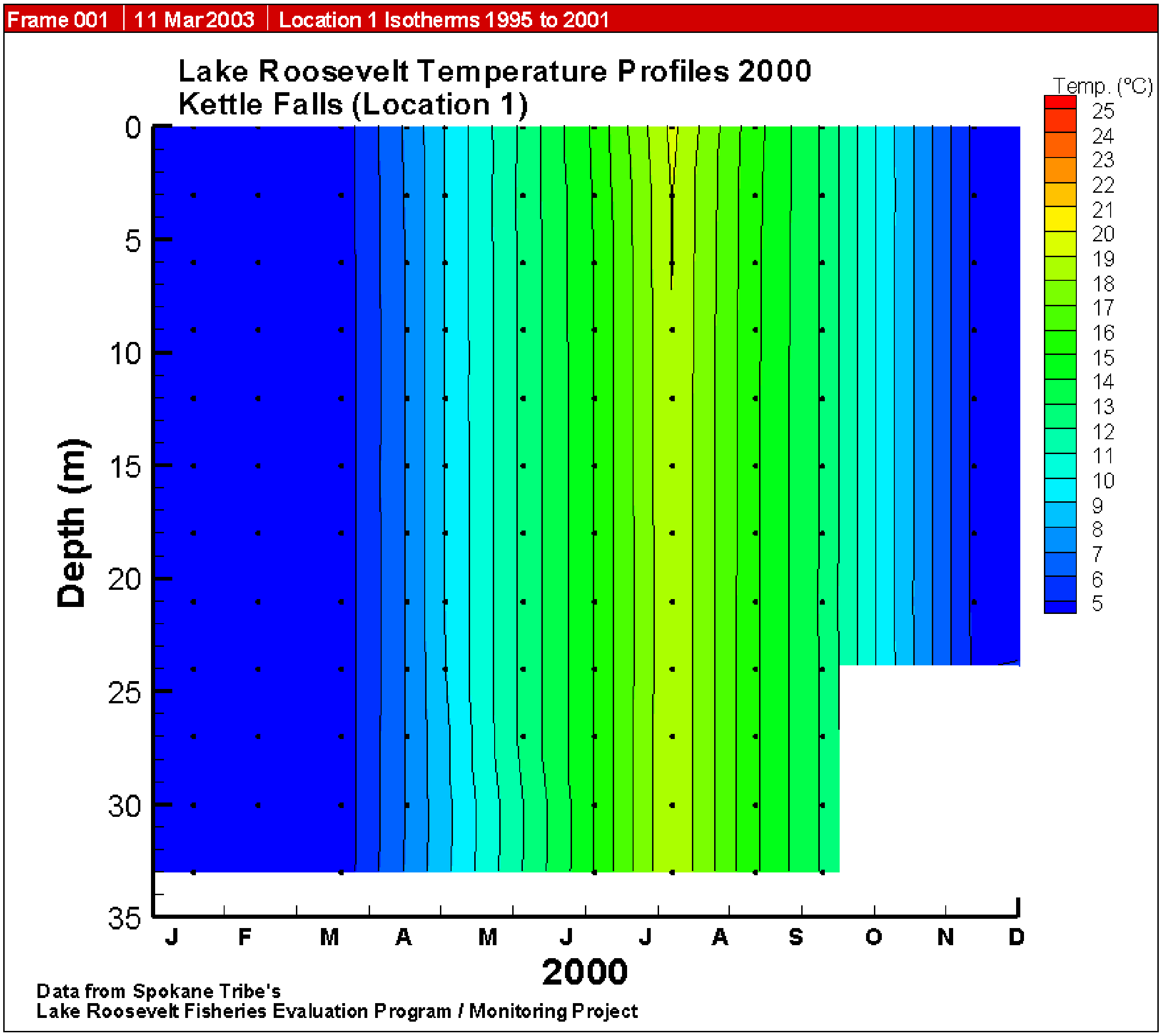
Temperature profile for water year 2000, Spokane River, Site ST-4



Temperature profile for water year 2000, Hunters, Site ST-3



Temperature profile for water year 2000, Gifford, Site ST-2



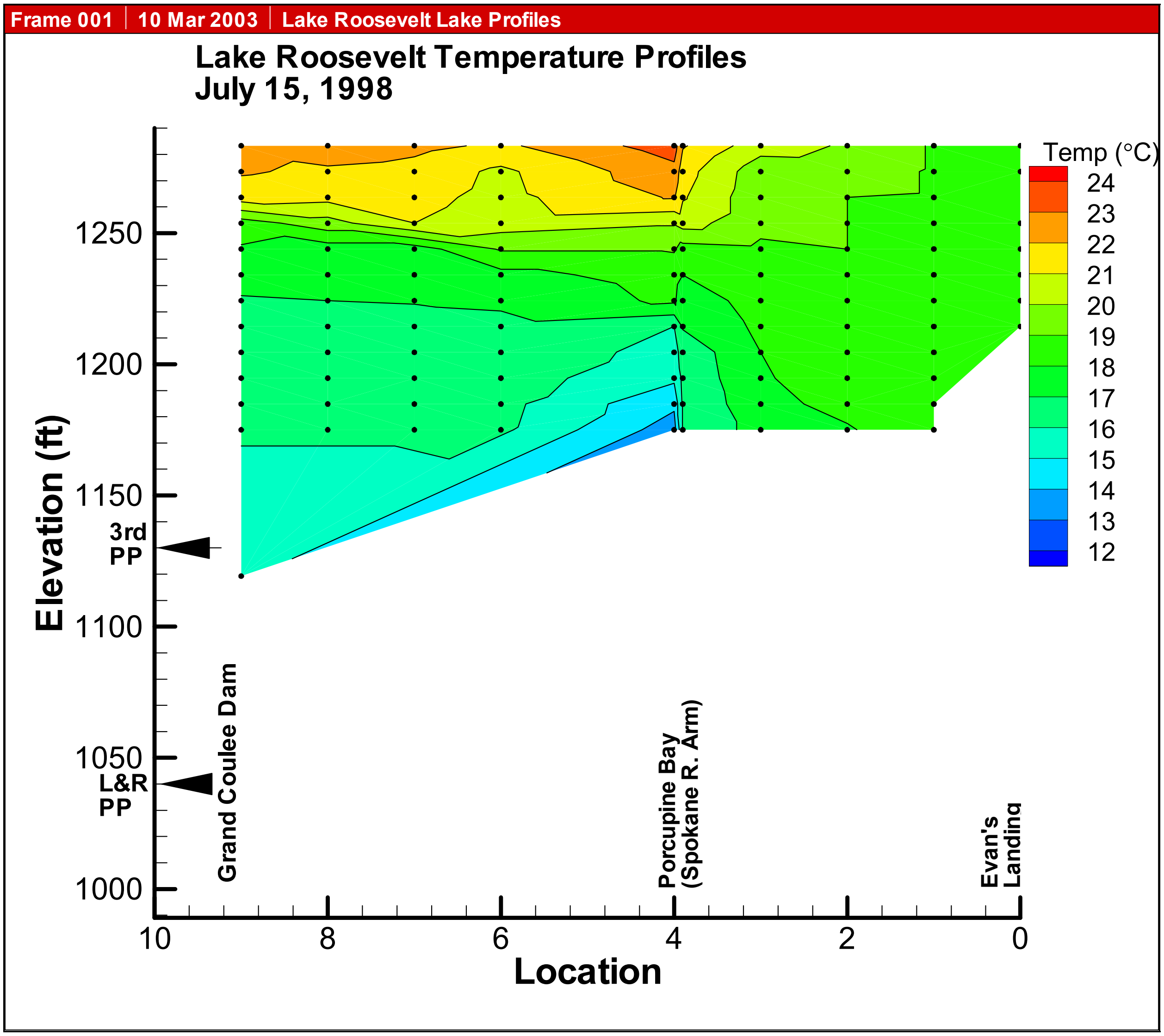
Temperature profile for water year 2000, Kettle Falls, Site ST-1

Appendix C

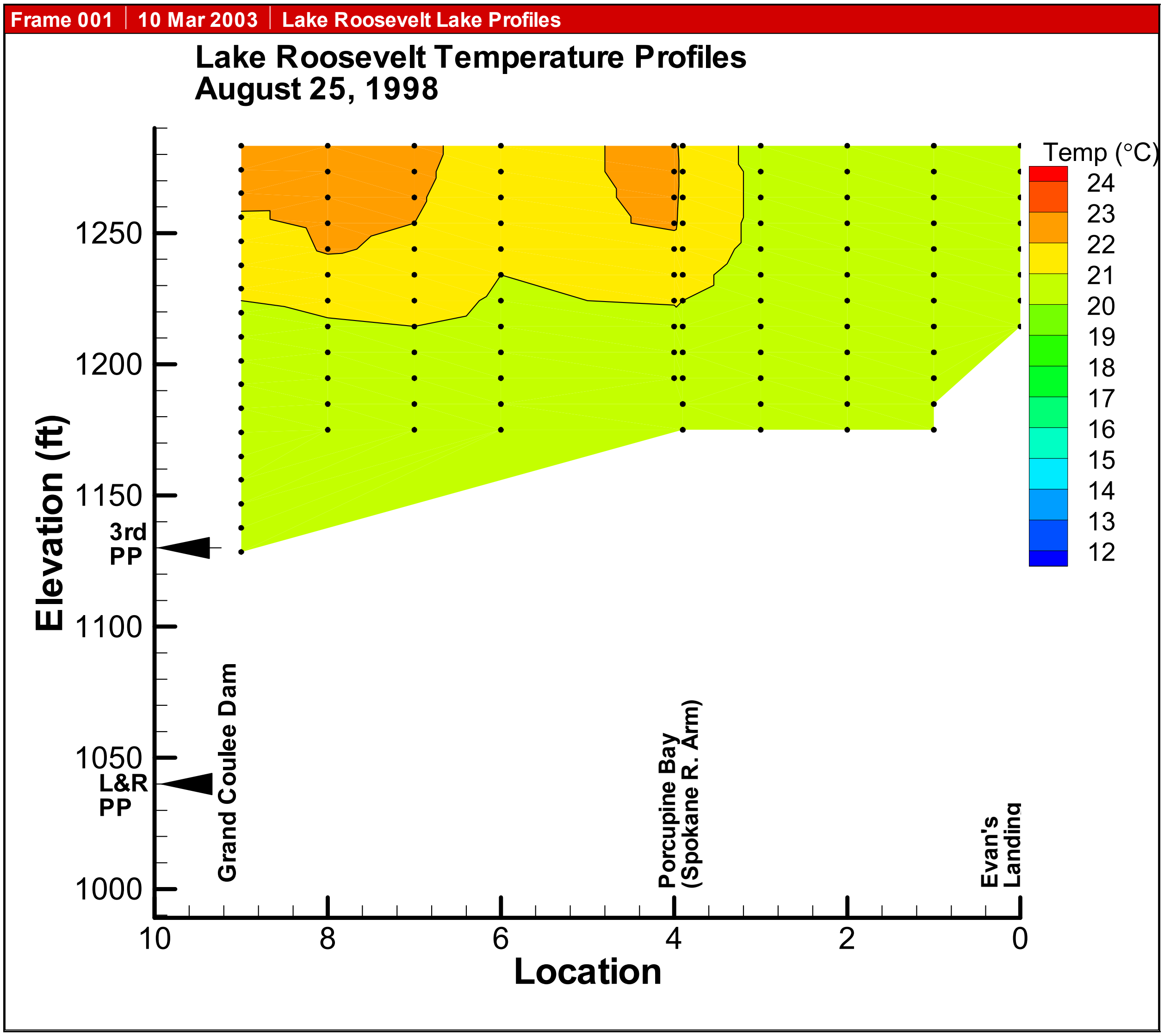
Composite longitudinal profiles showing Lake Roosevelt stratification patterns and changes over time

- *Longitudinal profiles of Lake Roosevelt, all sites, July 15, 1998*
- *Longitudinal profiles of Lake Roosevelt, all sites, August 25, 1998*
- *Longitudinal profiles of Lake Roosevelt, all sites, September 10, 1998*
- *Longitudinal profiles of Lake Roosevelt, all sites, October 7, 1998*
- *Longitudinal profiles of Lake Roosevelt, all sites, October 26, 1998*
- *Longitudinal profiles of Lake Roosevelt, all sites, November 16, 1998*
- *Longitudinal profiles of Lake Roosevelt, all sites, July 5, 2000*
- *Longitudinal profiles of Lake Roosevelt, all sites, July 25, 2000*
- *Longitudinal profiles of Lake Roosevelt, all sites, August 7, 2000*
- *Longitudinal profiles of Lake Roosevelt, all sites, August 21, 2000*
- *Longitudinal profiles of Lake Roosevelt, all sites, September 25, 2000*
- *Longitudinal profiles of Lake Roosevelt, all sites, October 9, 2000*
- *Longitudinal profiles of Lake Roosevelt, all sites, October 24, 2000*
- *Longitudinal profiles of Lake Roosevelt, all sites, November 15, 2000*

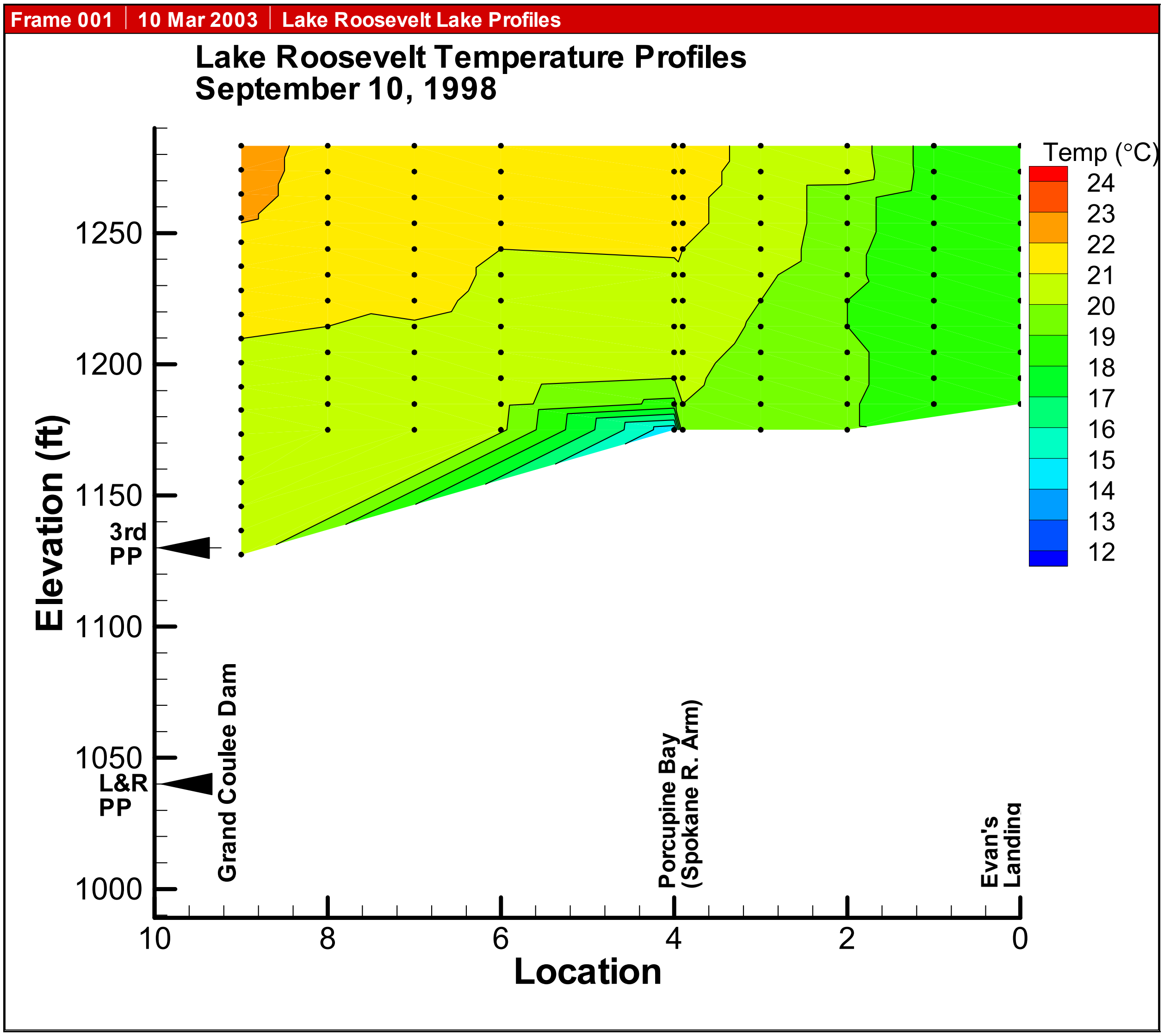
Note: Data at Grand Coulee forebay from Reclamation thermistor string combined with profiles in upper reservoir collected by Spokane Tribe of Indians.



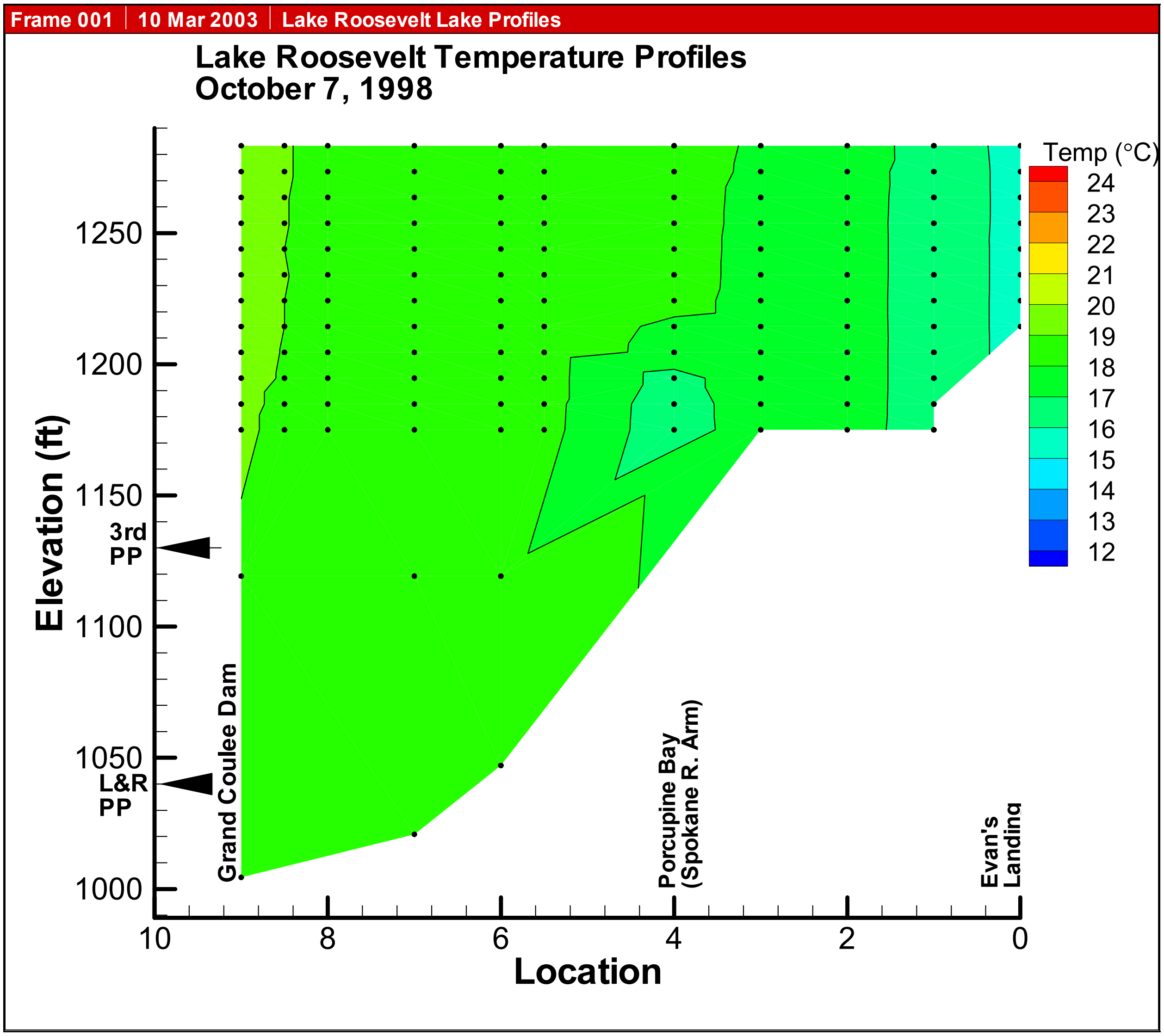
Longitudinal profiles of Lake Roosevelt, all sites, July 15, 1998



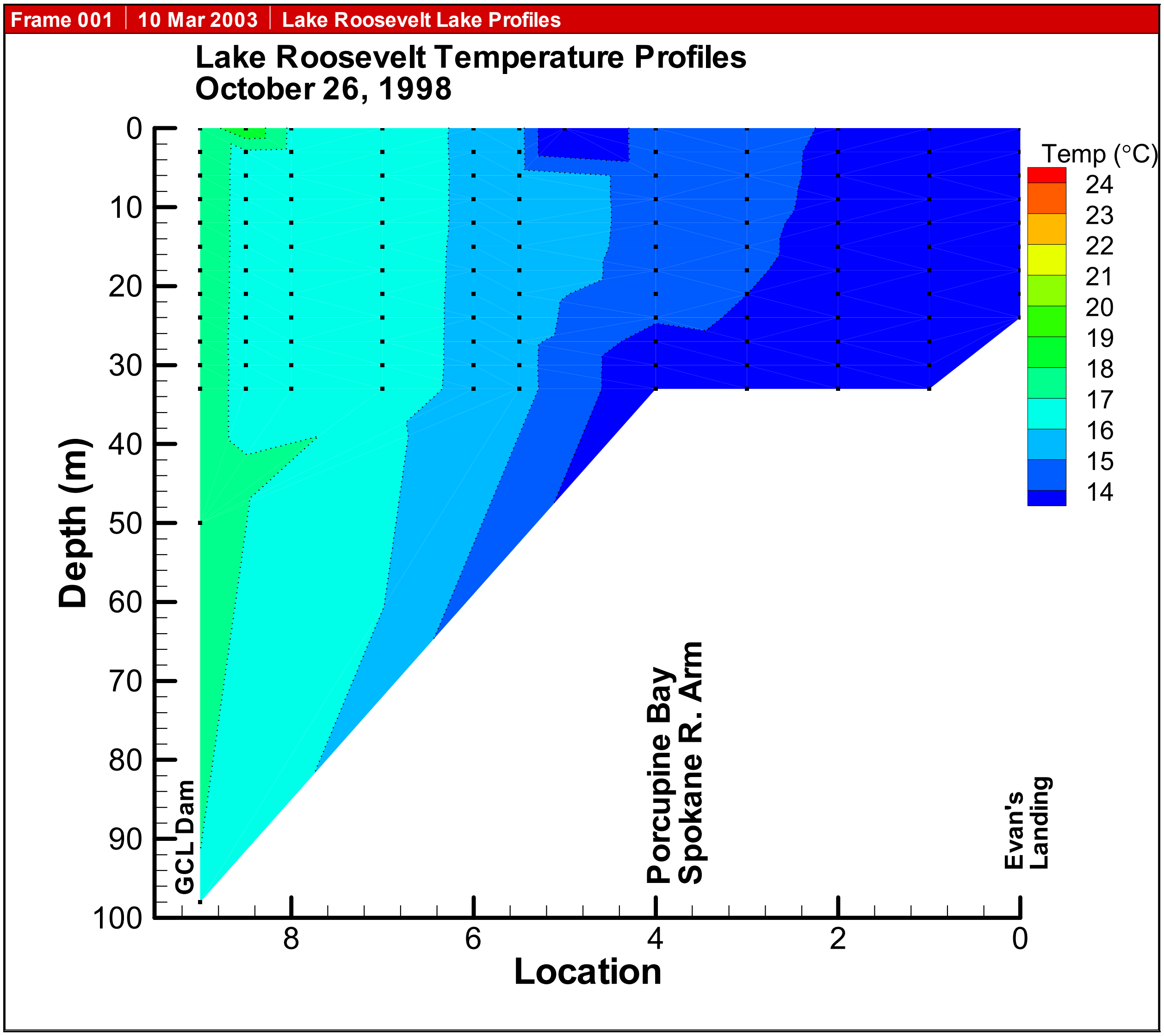
Longitudinal profiles of Lake Roosevelt, all sites, August 25, 1998



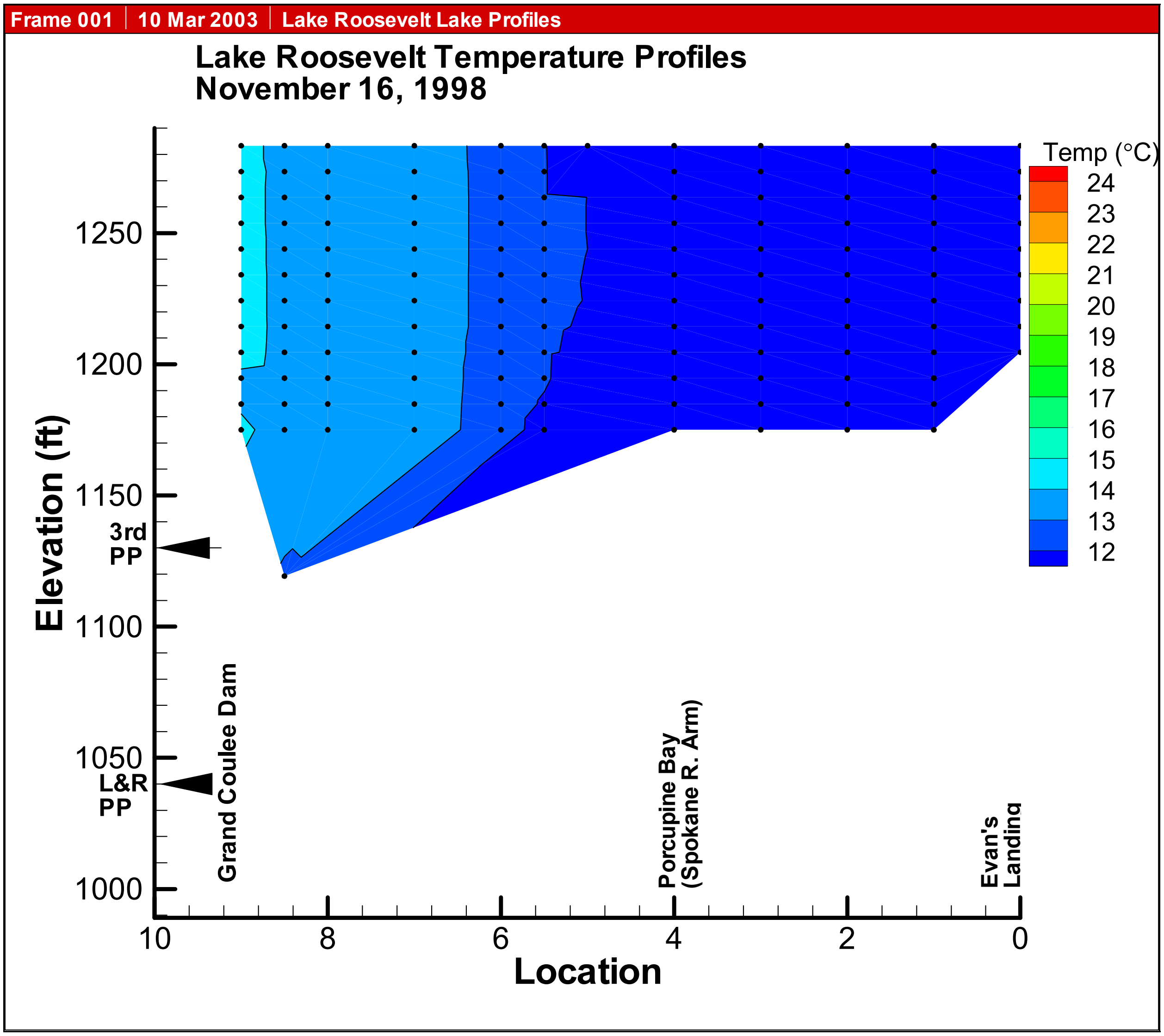
Longitudinal profiles of Lake Roosevelt, all sites, September 10, 1998



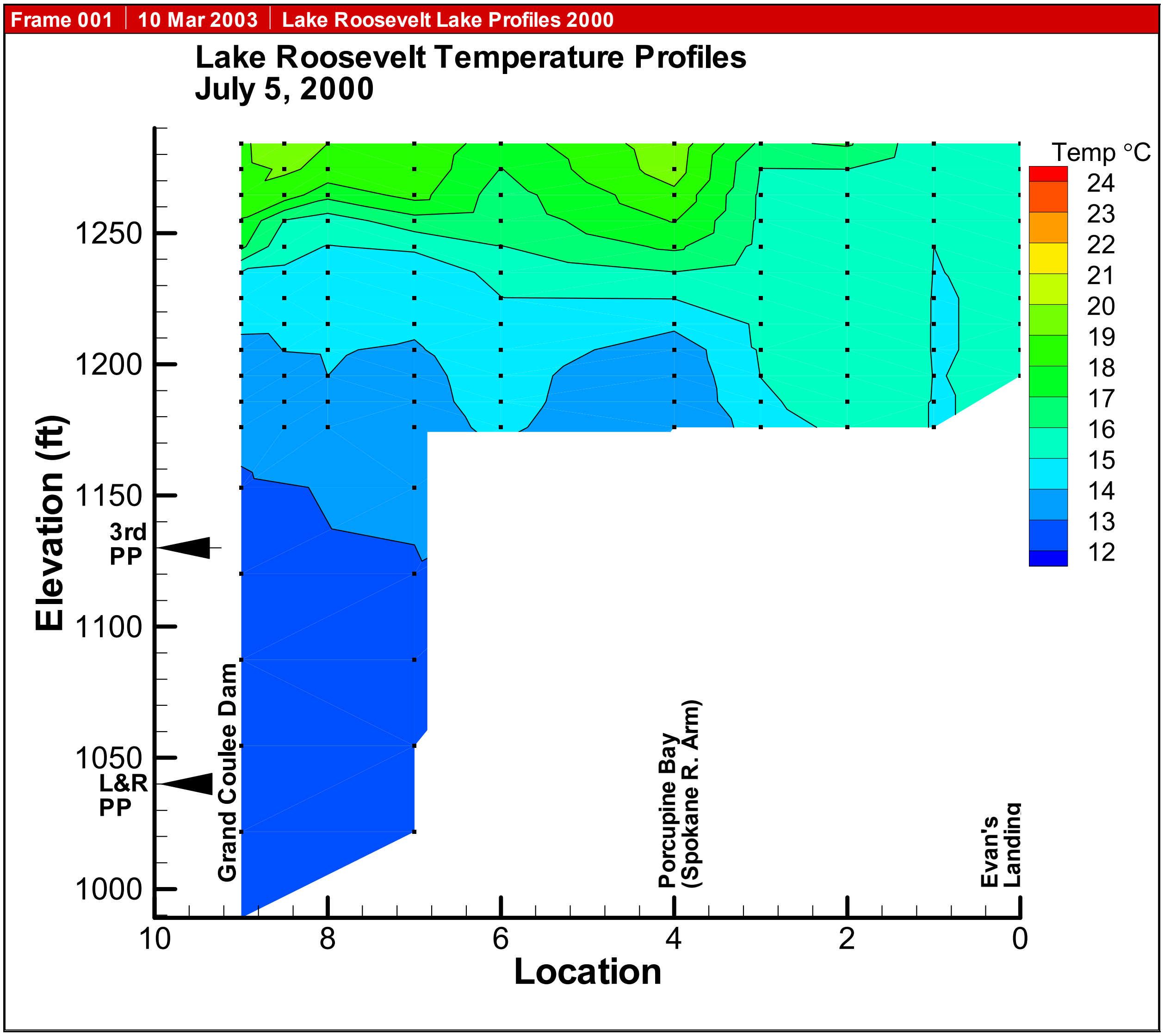
Longitudinal profiles of Lake Roosevelt, all sites, October 7, 1998



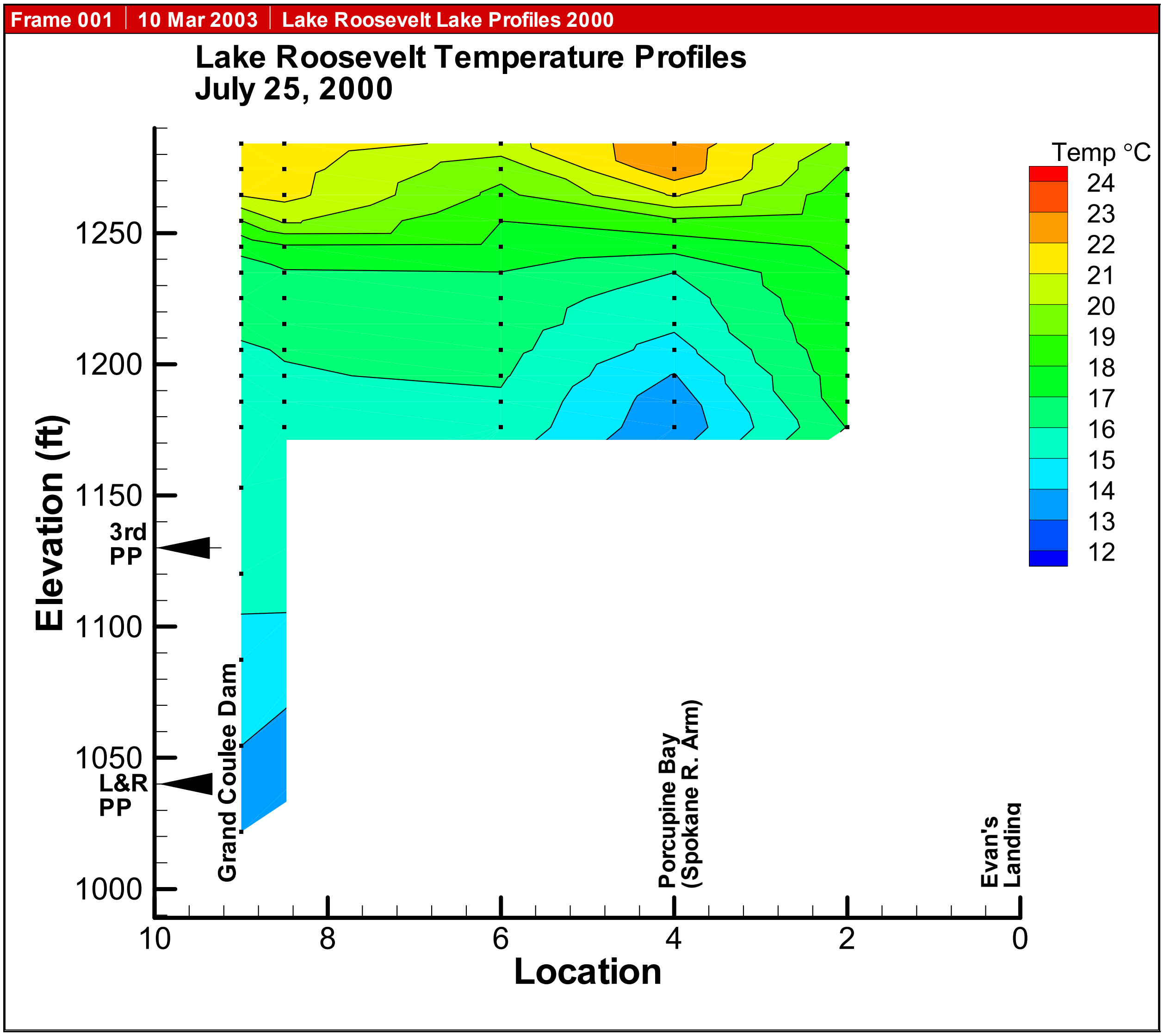
Longitudinal profiles of Lake Roosevelt, all sites, October 26, 1998



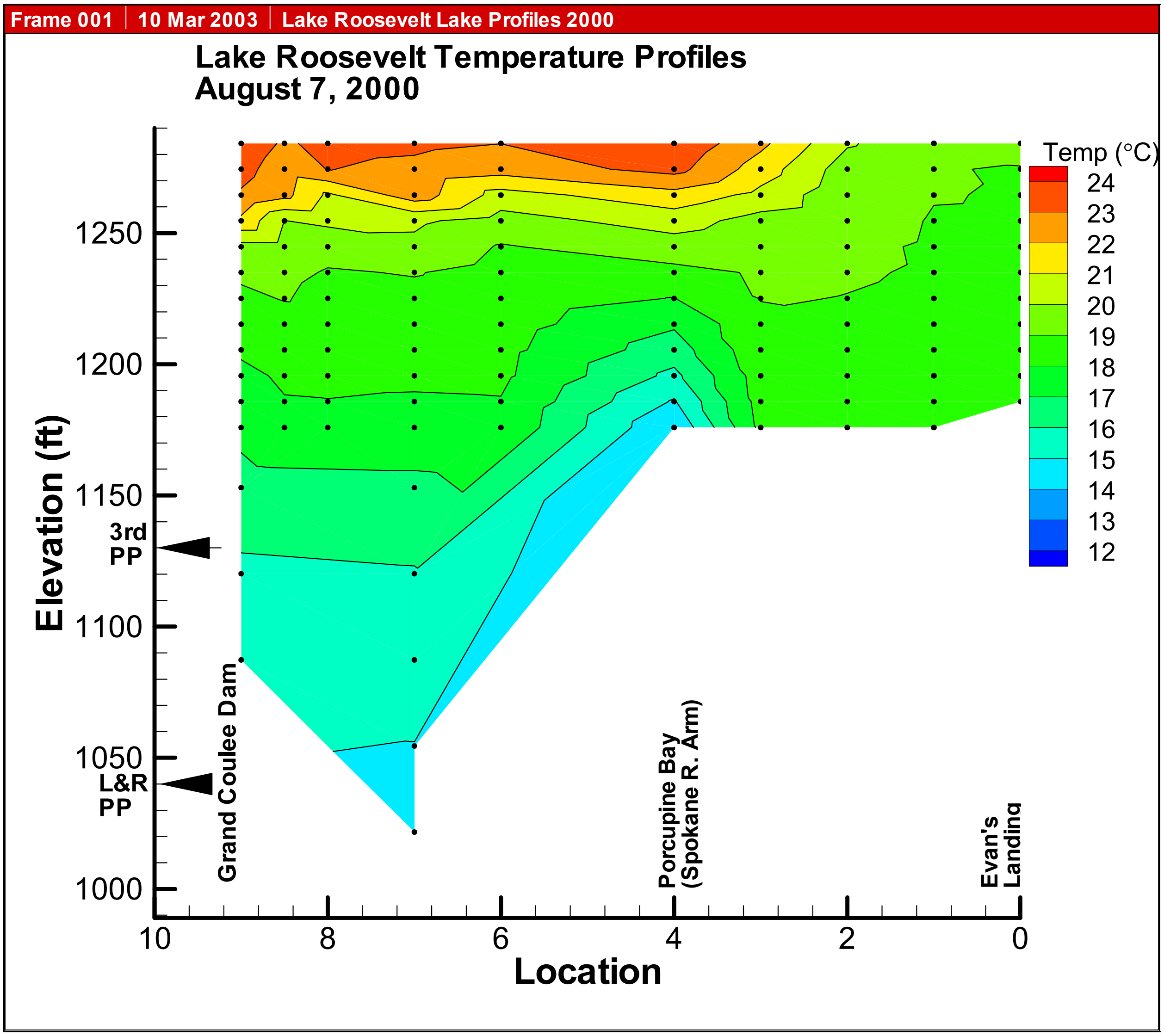
Longitudinal profiles of Lake Roosevelt, all sites, November 16, 1998



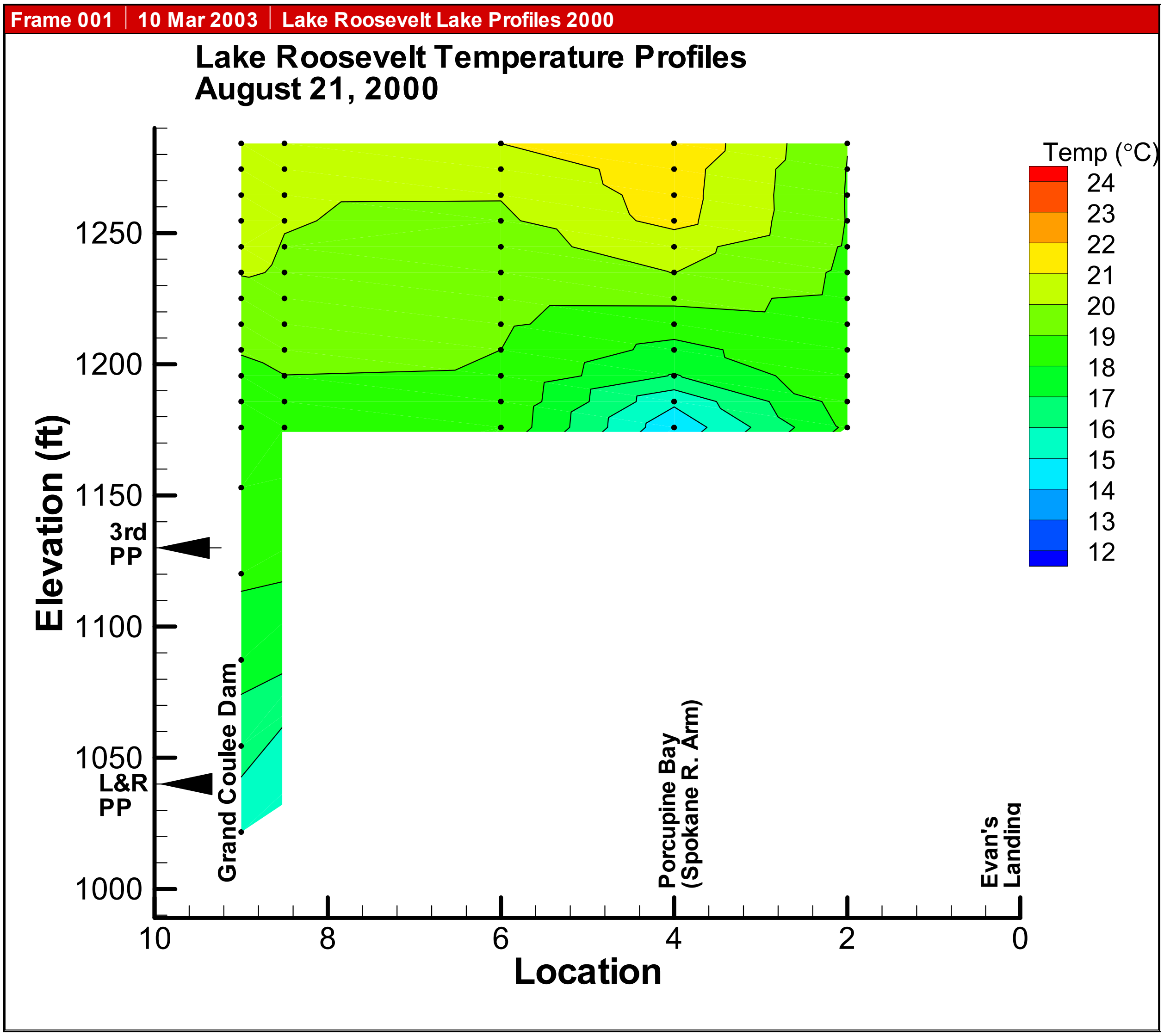
Longitudinal profiles of Lake Roosevelt, all sites, July 5, 2000



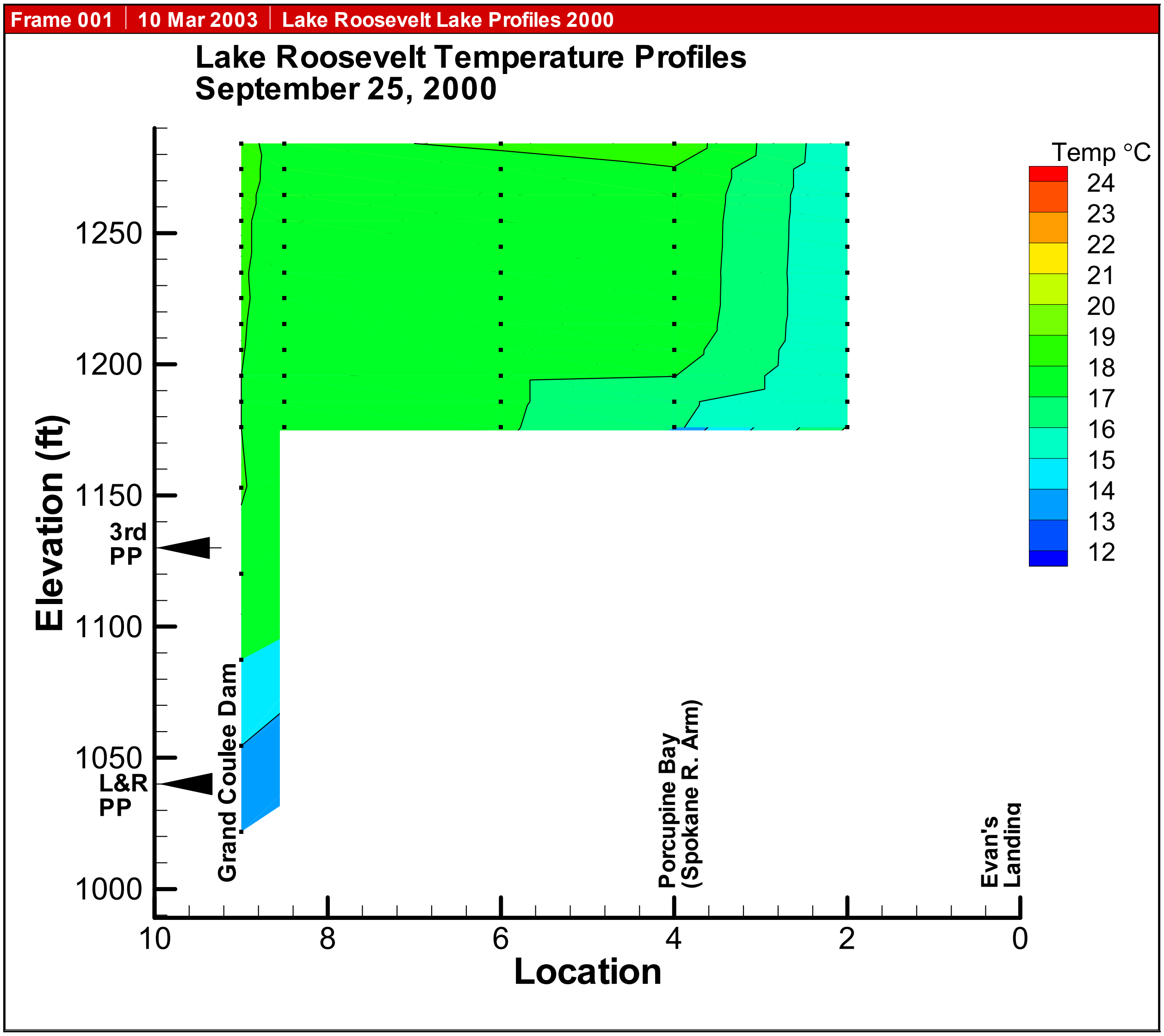
Longitudinal profiles of Lake Roosevelt, all sites, July 25, 2000



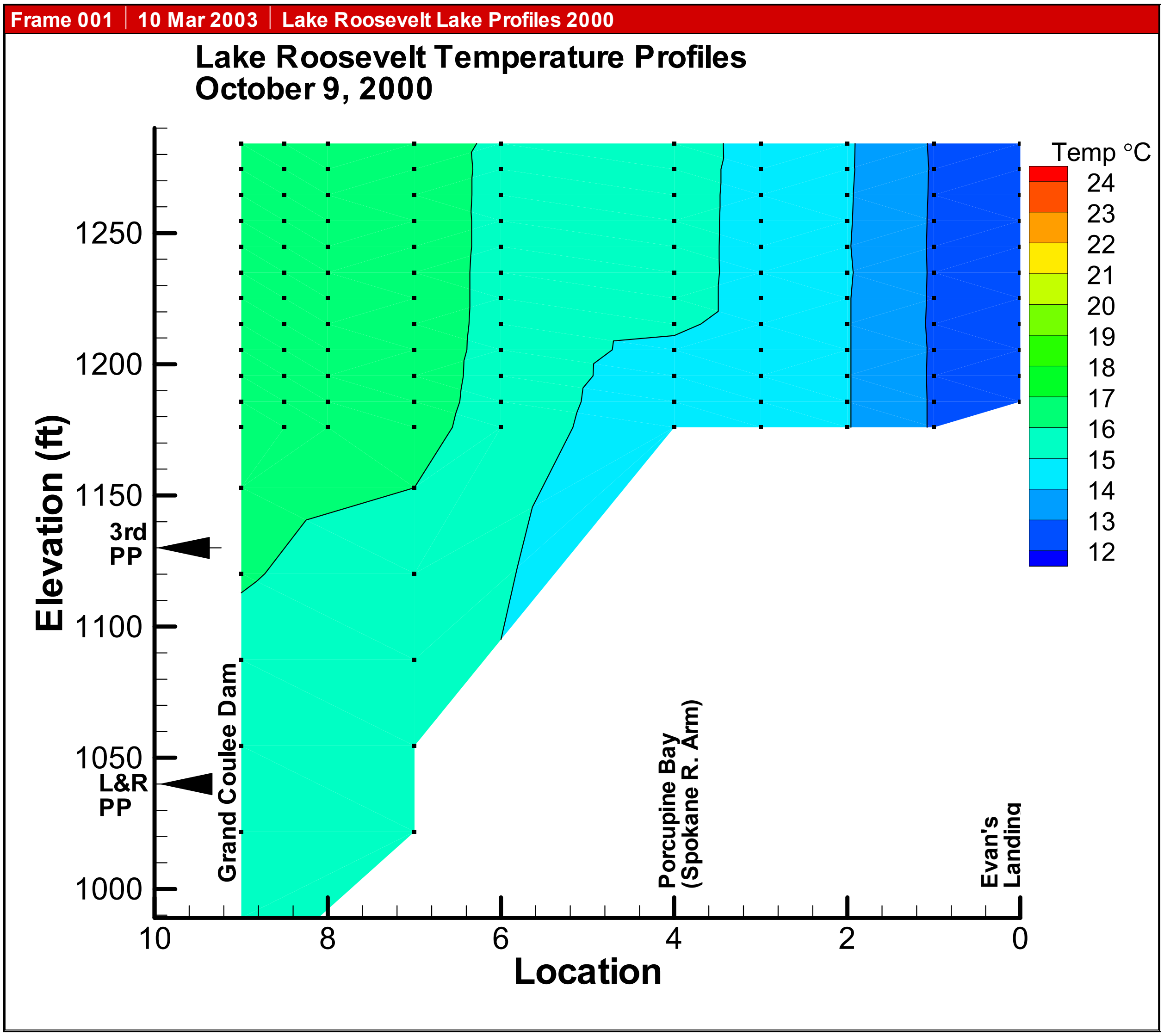
Longitudinal profiles of Lake Roosevelt, all sites, August 7, 2000



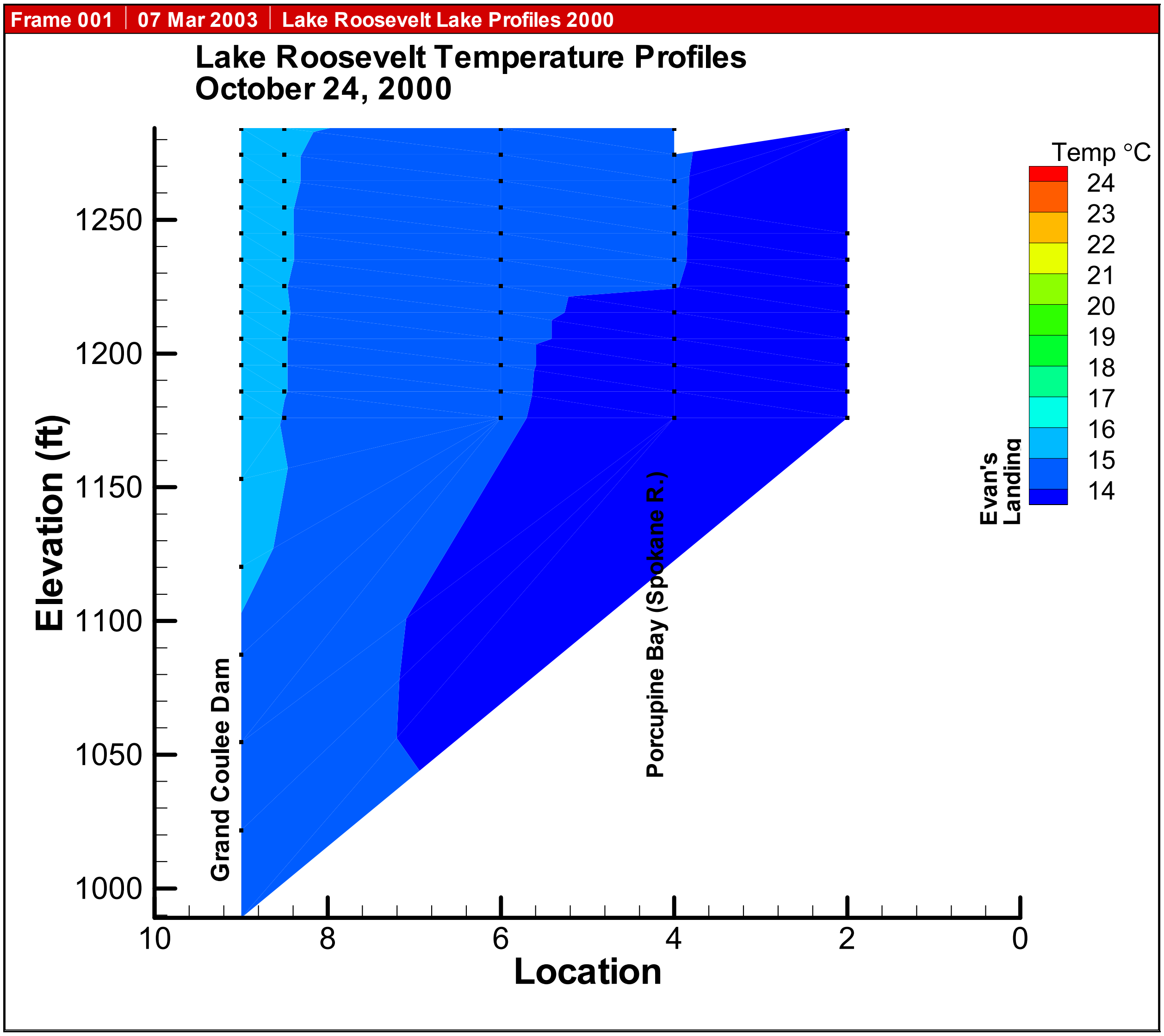
Longitudinal profiles of Lake Roosevelt, all sites, August 21, 2000



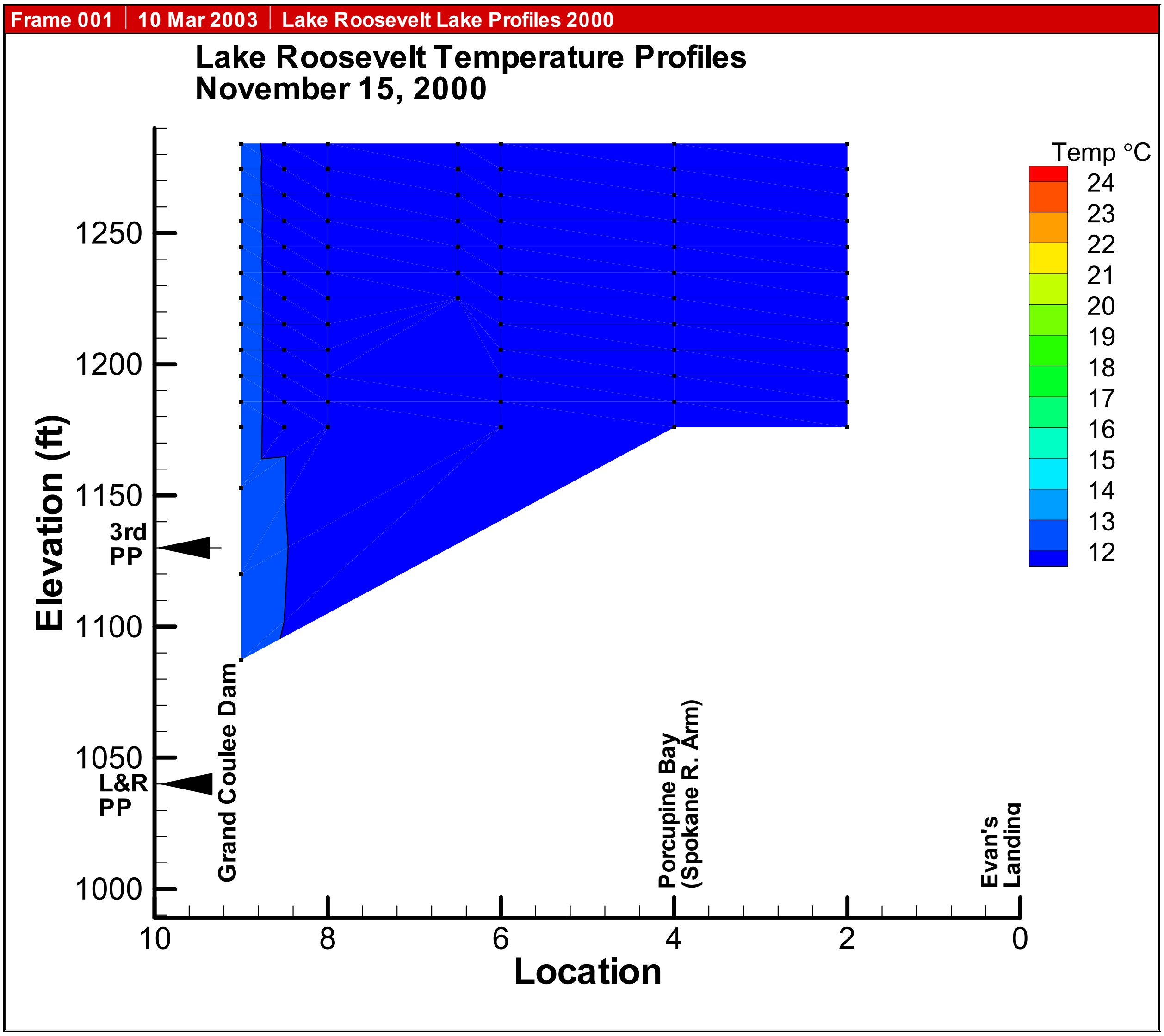
Longitudinal profiles of Lake Roosevelt, all sites, September 25, 2000



Longitudinal profiles of Lake Roosevelt, all sites, October 9, 2000



Longitudinal profiles of Lake Roosevelt, all sites, October 24, 2000



Longitudinal profiles of Lake Roosevelt, all sites, November 15, 2000

Appendix D

Preliminary cost estimate worksheets for multi-level intake structures

- *Cost estimate worksheets for Left Powerplant selective withdrawal structures*
- *Cost estimate worksheets for Right Powerplant selective withdrawal structures*
- *Cost estimate worksheets for Banks Lake P/G selective withdrawal structures*

Cost estimate worksheets for Left Powerplant selective withdrawal structures

CODE: D-8170 **ESTIMATE WORKSHEET** SHEET 1 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
LEFT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE
FULL-HEIGHT SHUTTERS WITH LOW LEVEL WITHDRAWAL
APPRAISAL STUDY - MARCH 2003
Assumed Water Surface during construction: El. 1290
WOID: GCP17

PROJECT: **Columbia Basin - Washington**

REGION: **Pacific Northwest**

FILE: Coulee_TCD_LeftPP.xls

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Quantities are for:					
		Full height shutter structures enclosing all nine penstock intakes					
		with four 50' x 50' gates in each shutter to control withdrawal level					
		Q/unit= 5,000 cfs					
		Quantities extrapolated from Shasta TCD Final Estimate completed in 1994.					
		Limited calculations were made to adjust quantities.					
	1	Mobilization		1	LS	$8,700,000.00	$8,700,000.00
	2	Mobilization (underwater work)			Included in above item #1		
	3	Concrete removals:	D8120				
		In dry (at 36 locations on U/S and D/S face)		300	CY	$1,000.00	$300,000.00
		Between 0 and 100 feet (at 18 locations on U/S face)		110	CY	$1,800.00	$198,000.00
		Between 300 and 400 feet (at 36 locations on U/S face)		0.5	CY	$30,000.00	$15,000.00
	4	Furnish and place reinforced concrete	D8120	135	CY	$800.00	$108,000.00
		in dry, f'c= 4000 psi (incl. cement)					
	5	Furnish and place concrete reinforcement (150#/CY)	D8120	20,250	LBS	$0.80	$16,200.00
	6	Pressure grout dam connection plates: (2 CF/Plate)	D8120				
		In Dry (2 plates /DC1)		36	EA	$5,000.00	$180,000.00
		Between 0 and 100 feet		36	EA	$10,000.00	$360,000.00
		Between 101 and 200 feet		36	EA	$22,000.00	$792,000.00
		Between 201 and 300 feet		36	EA	$42,000.00	$1,512,000.00
		Between 300 and 400 feet		36	EA	$62,000.00	$2,232,000.00
	7	Setups per dam connection:	D8120				
		In Dry		36	EA	$930.00	$33,480.00
		Between 0 and 100 feet		72	EA	$2,200.00	$158,400.00
		Between 101 and 200 feet		72	EA	$3,800.00	$273,600.00
		Between 201 and 300 feet		72	EA	$8,100.00	$583,200.00
		Between 300 and 400 feet		72	EA	$14,000.00	$1,008,000.00
		Assumed two setups per dam connection:					
		Setup 1. Attach dam connection steel to dam.					
		Setup 2. Attach shutters and rigid frames to dam connections.					
		(DC plate grouting covered in Item 6, anchors covered in Items 8, 9. and 10)					
		Subtotal this Sheet					$16,469,880.00

QUANTITIES		PRICES	
BY D. LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170 **ESTIMATE WORKSHEET** SHEET 2 OF 4

FEATURE: 17-Jun-03 ***GRAND COULEE TEMPERATURE MANAGEMENT STUDY*** ***LEFT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE*** ***FULL-HEIGHT SHUTTERS WITH LOW LEVEL WITHDRAWAL*** ***APPRAISAL STUDY - MARCH 2003*** ***Assumed Water Surface during construction: El. 1290*** **WOID: GCP17**	**PROJECT:** **Columbia Basin - Washington** **REGION:** **Pacific Northwest** **FILE:**

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	8	Furnish and install 20 mm dia. SS expansion anchors,	D8120				
		6-inch embed (Hilti HSLG-R M 20/30)					
		Between 0 and 100 feet		36	EA	$750.00	$27,000.00
		Between 101 and 200 feet		72	EA	$1,300.00	$93,600.00
		Between 201 and 300 feet		72	EA	$1,900.00	$136,800.00
		Between 300 and 400 feet		72	EA	$2,500.00	$180,000.00
	9	Furnish and install 1 3/8-inch diameter Williams	D8120				
		Hollowcore (R1HG) anchors (epoxy coated):					
		In Dry (Embed 3 feet)		72	EA	$4,400.00	$316,800.00
		Between 0 and 100 feet (Embed 3 feet)		144	EA	$2,300.00	$331,200.00
		Between 101 and 200 feet (Embed 3 feet)		144	EA	$4,100.00	$590,400.00
		Between 201 and 300 feet (Embed 3 feet)		144	EA	$15,000.00	$2,160,000.00
		Between 300 and 400 feet (Embed 3 feet)		144	EA	$23,000.00	$3,312,000.00
	10	Furnish and install 2-inch diameter Williams	D8120				
		Hollowcore (R1HG) anchors (epoxy coated):					
		In Dry (Embed 21 feet from top of dam)		72	EA	$5,000.00	$360,000.00
		Between 0 and 100 feet (Embed 4 feet)		72	EA	$3,000.00	$216,000.00
		Between 101 and 200 feet (Embed 4 feet)		144	EA	$5,000.00	$720,000.00
		Between 201 and 300 feet (Embed 4 feet)		144	EA	$16,000.00	$2,304,000.00
		Between 300 and 400 feet (Embed 4 feet)		144	EA	$25,000.00	$3,600,000.00
	11	Furnish and install 2 1/2-inch dia. post-tension bars,	D8120	144	EA	$6,000.00	$864,000.00
		in dry, length/bar=30 feet, 6-inch dia hole,					
		(Williams 150 ksi All-thread bar)					
	12	Furnish and install dam connection steel:	D8120				
		Plates, rods, built-up members (A572/50, coated)		700,000	LBS	$3.50	$2,450,000.00
		Forgings (A668F, galv)-Pins, shackles, turnbuckles		150,000	LBS	$10.00	$1,500,000.00
	13	Furnish and erect shutter structural steel:	D8120				
		Shapes, plates, built-up members (A572/50, coated)		18,900,000	LBS	$3.00	$56,700,000.00
		5-inch dia. threaded rods, (A572/50, coated),		530,000	LBS	$8.00	$4,240,000.00
		L/rod=55 feet, Number req'd= 144					
		(Progressive lowering installation similar to Shasta TCD.)					
		Subtotal this Sheet					$80,101,800.00

QUANTITIES		PRICES	
BY Dick LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170

ESTIMATE WORKSHEET

SHEET 3 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
LEFT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE
FULL-HEIGHT SHUTTERS WITH LOW LEVEL WITHDRAWAL
APPRAISAL STUDY - MARCH 2003

Assumed Water Surface during construction: El. 1290

WOID: GCP17

PROJECT: Columbia Basin - Washington

REGION: Pacific Northwest

FILE:

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	14	Furnish and install cladding panels:	D8120				
		Structural Steel (A572/50, coated):		4,384,000	LBS	$2.00	$8,768,000.00
		Steel bridge plank (6x2 - 10 gage - 8.0 lb/sf)		137,000	SF	$15.00	$2,055,000.00
		(Lowered into shutter slots from top of dam.)					
	15	Furnish and install closure panels underwater (0-400ft)	D8120				
		btwn shutters and end shutters and dam:					
		Structural Steel (A572/50, coated):		1,168,000	LBS	$6.00	$7,008,000.00
		Steel bridge plank (6x2 - 10 gage - 8.0 lb/sf)		36,500	SF	$50.00	$1,825,000.00
	16	Miscellaneous Metalwork	D8120	350,000	LBS	$5.20	$1,820,000.00
	17	Furnish and install 5-foot high chain link fence	D8120	600	LF	$30.00	$18,000.00
	18	F&I 1/4" SS gate guide plates	D8120	325,000	LBS	$12.00	$3,900,000.00
	19	Furnish and install new trashracks (A36, coated)	D8410	3,928,500	LBS	$2.60	$10,214,100.00
	20	Furnish and install Upper Gates: (9 required)	D8410				
		Gate steel (A36, A572/50) (117,300 lbs ea.)		1,055,700	LBS	$5.80	$6,123,060.00
		Gate Hoists (Incl. Sheaves, wire rope) (65,000 lbs/ea)		585,000	LBS	$7.00	$4,095,000.00
	21	Furnish and install Middle Gates: (9 required)	D8410				
		Gate steel (A36, A572/50) (117,300 lbs ea.)		1,055,700	LBS	$5.80	$6,123,060.00
		Gate Hoists (Incl. Sheaves, wire rope) (65,000 lbs/ea)		585,000	LBS	$7.00	$4,095,000.00
		Subtotal this Sheet					$56,044,220.00

QUANTITIES		PRICES	
BY Dick LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170

ESTIMATE WORKSHEET

SHEET 4 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
LEFT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE
FULL-HEIGHT SHUTTERS WITH LOW LEVEL WITHDRAWAL
APPRAISAL STUDY - MARCH 2003

Assumed Water Surface during construction: El. 1290

WOID: GCP17

PROJECT: **Columbia Basin - Washington**

REGION: **Pacific Northwest**

FILE:

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	22	Furnish and install Pressure Relief Gates: (9 required)	D8410				
		Gate steel (A36, A572/50) (210,000 lbs/ea.)		1,890,000	LBS	$5.80	$10,962,000.00
		Gate Hoists (Incl. Sheaves, wire rope) (110,000 lbs/ea)		990,000	LBS	$7.00	$6,930,000.00
	23	Furnish and install Low Level Gates: (9 required)	D8410				
		Gate steel (A36, A572/50) (117,300 lbs ea.)		1,055,700	LBS	$5.80	$6,123,060.00
		Gate Hoists (Incl. Sheaves, wire rope) (65,000 lbs/ea)		585,000	LBS	$7.00	$4,095,000.00
	24	Furnish and install cathodic protection system	D8180	9	EA	$70,000.00	$630,000.00
		(1 system per unit)					
	25	Furnish, install, and test all electrical equipment	D8440	1	LS	$300,000.00	$300,000.00
	26	Furnish, install , and test temperature monitoring	D8410	1	LS	$300,000.00	$300,000.00
		equipment					
	27	Perform gate travel tests (4 per unit)	D8410	36	EA	$7,000.00	$252,000.00
		Subtotal this Sheet					$29,592,060.00
		Subtotal (All Sheets)					**$182,207,960.00**
		Unlisted Items (20%)					**$37,792,040.00**
		Contract Cost					**$220,000,000.00**
		Contingencies (25%)					**$50,000,000.00**
		Field Cost					**$270,000,000.00**

QUANTITIES		PRICES	
BY Dick LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

Cost estimate worksheets for Right Powerplant selective withdrawal structures

CODE: D-8170

ESTIMATE WORKSHEET

SHEET 1 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
RIGHT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE
FULL-HEIGHT SHUTTERS
APPRAISAL STUDY - MARCH 2003

Assumed Water Surface during construction: El. 1290

WOID: GCP17

PROJECT: Columbia Basin - Washington

REGION: Pacific Northwest

FILE: Coulee_TCD_RightPP.xls

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Quantities are for:					
		Full height shutter structures enclosing all nine penstock intakes					
		with 50' x 50' gates in each shutter to control withdrawal level					
		Q/unit= 5,000 cfs, Topography affects number of gates.					
		Quantities extrapolated from Shasta TCD Final Estimate completed in 1994.					
		Limited calculations were made to adjust quantities.					
	1	Mobilization		1	LS	$7,900,000.00	$7,900,000.00
	2	Mobilization (underwater work)			Included in above Item #1		
	3	Concrete removals:	D8120				
		In dry (at 36 locations on U/S and D/S face)		300	CY	$1,000.00	$300,000.00
		Between 0 and 100 feet (at 18 locations on U/S face)		110	CY	$1,800.00	$198,000.00
		Between 300 and 400 feet (at 24 locations on U/S face)		0.3	CY	$30,000.00	$9,000.00
	4	Furnish and place reinforced concrete	D8120	135	CY	$800.00	$108,000.00
		in dry, f'c= 4000 psi (incl. cement)					
	5	Furnish and place concrete reinforcement (150#/CY)	D8120	20,250	LBS	$0.80	$16,200.00
	6	Pressure grout dam connection plates: (2 CF/Plate)	D8120				
		In Dry (2 plates /DC1)		36	EA	$5,000.00	$180,000.00
		Between 0 and 100 feet		36	EA	$10,000.00	$360,000.00
		Between 101 and 200 feet		36	EA	$22,000.00	$792,000.00
		Between 201 and 300 feet		36	EA	$42,000.00	$1,512,000.00
		Between 300 and 400 feet		24	EA	$62,000.00	$1,488,000.00
	7	Setups per dam connection:	D8120				
		In Dry		36	EA	$930.00	$33,480.00
		Between 0 and 100 feet		72	EA	$2,200.00	$158,400.00
		Between 101 and 200 feet		72	EA	$3,800.00	$273,600.00
		Between 201 and 300 feet		72	EA	$8,100.00	$583,200.00
		Between 300 and 400 feet		48	EA	$14,000.00	$672,000.00
		Assumed two setups per dam connection:					
		Setup 1. Attach dam connection steel to dam.					
		Setup 2. Attach shutters and rigid frames to dam connections.					
		(DC plate grouting covered in Item 6, anchors covered in Items 8, 9. and 10)					
		Subtotal this Sheet					$14,583,880.00

QUANTITIES		PRICES	
BY D. LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170 | **ESTIMATE WORKSHEET** | SHEET 2 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
RIGHT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE
FULL-HEIGHT SHUTTERS
APPRAISAL STUDY - MARCH 2003
Assumed Water Surface during construction: El. 1290

WOID: GCP17

PROJECT: Columbia Basin - Washington

REGION: Pacific Northwest

FILE:

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	8	Furnish and install 20 mm dia. SS expansion anchors,	D8120				
		6-inch embed (Hilti HSLG-R M 20/30)					
		Between 0 and 100 feet		36	EA	$750.00	$27,000.00
		Between 101 and 200 feet		72	EA	$1,300.00	$93,600.00
		Between 201 and 300 feet		72	EA	$1,900.00	$136,800.00
		Between 300 and 400 feet		48	EA	$2,500.00	$120,000.00
	9	Furnish and install 1 3/8-inch diameter Williams	D8120				
		Hollowcore (R1HG) anchors (epoxy coated):					
		In Dry (Embed 3 feet)		72	EA	$4,400.00	$316,800.00
		Between 0 and 100 feet (Embed 3 feet)		144	EA	$2,300.00	$331,200.00
		Between 101 and 200 feet (Embed 3 feet)		144	EA	$4,100.00	$590,400.00
		Between 201 and 300 feet (Embed 3 feet)		144	EA	$15,000.00	$2,160,000.00
		Between 300 and 400 feet (Embed 3 feet)		96	EA	$23,000.00	$2,208,000.00
	10	Furnish and install 2-inch diameter Williams	D8120				
		Hollowcore (R1HG) anchors (epoxy coated):					
		In Dry (Embed 21 feet from top of dam)		72	EA	$5,000.00	$360,000.00
		Between 0 and 100 feet (Embed 4 feet)		72	EA	$3,000.00	$216,000.00
		Between 101 and 200 feet (Embed 4 feet)		144	EA	$5,000.00	$720,000.00
		Between 201 and 300 feet (Embed 4 feet)		144	EA	$16,000.00	$2,304,000.00
		Between 300 and 400 feet (Embed 4 feet)		96	EA	$25,000.00	$2,400,000.00
	11	Furnish and install 2 1/2-inch dia. post-tension bars,	D8120	144	EA	$6,000.00	$864,000.00
		in dry, length/bar=30 feet, 6-inch dia hole,					
		(Williams 150 ksi All-thread bar)					
	12	Furnish and install dam connection steel:	D8120				
		Plates, rods, built-up members (A572/50, coated)		670,000	LBS	$3.50	$2,345,000.00
		Forgings (A668F, galv)-Pins, shackles, turnbuckles		140,000	LBS	$10.00	$1,400,000.00
	13	Furnish and erect shutter structural steel:	D8120				
		Shapes, plates, built-up members (A572/50, coated)		18,300,000	LBS	$3.00	$54,900,000.00
		5-inch dia. threaded rods, (A572/50, coated),		530,000	LBS	$8.00	$4,240,000.00
		L/rod=55 feet, Number req'd= 144					
		(Progressive lowering installation similar to Shasta TCD.)					
		Subtotal this Sheet					$75,732,800.00

QUANTITIES		PRICES	
BY: Dick LaFond	CHECKED	BY: D.L. Maag	CHECKED
DATE PREPARED: 6/17/03	APPROVED	DATE: 17-Jun-03	PRICE LEVEL: Appraisal

CODE: D-8170 | **ESTIMATE WORKSHEET** | SHEET 3 OF 4

FEATURE: 17-Jun-03 *GRAND COULEE TEMPERATURE MANAGEMENT STUDY* *RIGHT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE* *FULL-HEIGHT SHUTTERS* *APPRAISAL STUDY - MARCH 2003* *Assumed Water Surface during construction: El. 1290* **WOID: GCP17**	**PROJECT:** Columbia Basin - Washington **REGION:** Pacific Northwest **FILE:**

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	14	Furnish and install cladding panels:	D8120				
		Structural Steel (A572/50, coated):		3,981,000	LBS	$2.00	$7,962,000.00
		Steel bridge plank (6x2 - 10 gage - 8.0 lb/sf)		124,400	SF	$15.00	$1,866,000.00
		(Lowered into shutter slots from top of dam.)					
	15	Furnish and install closure panels underwater (0-400ft)	D8120				
		btwn shutters and end shutters and dam:					
		Structural Steel (A572/50, coated):		1,022,000	LBS	$6.00	$6,132,000.00
		Steel bridge plank (6x2 - 10 gage - 8.0 lb/sf)		32,000	SF	$50.00	$1,600,000.00
	16	Miscellaneous Metalwork	D8120	350,000	LBS	$5.20	$1,820,000.00
	17	Furnish and install 5-foot high chain link fence	D8120	600	LF	$30.00	$18,000.00
	18	F&I 1/4" SS gate guide plates	D8120	275,000	LBS	$12.00	$3,300,000.00
	19	Furnish and install new trashracks (A36, coated)	D8410	3,403,500	LBS	$2.60	$8,849,100.00
	20	Furnish and install Upper Gates: (9 required)	D8410				
		Gate steel (A36, A572/50) (117,300 lbs ea.)		1,055,700	LBS	$5.80	$6,123,060.00
		Gate Hoists (Incl. Sheaves, wire rope) (65,000 lbs/ea)		585,000	LBS	$7.00	$4,095,000.00
	21	Furnish and install Middle Gates: (9 required)	D8410				
		Gate steel (A36, A572/50) (117,300 lbs ea.)		1,055,700	LBS	$5.80	$6,123,060.00
		Gate Hoists (Incl. Sheaves, wire rope) (65,000 lbs/ea)		585,000	LBS	$7.00	$4,095,000.00
		Subtotal this Sheet					$51,983,220.00

QUANTITIES		PRICES	
BY Dick LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170

ESTIMATE WORKSHEET

SHEET 4 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
RIGHT POWERPLANT - SELECTIVE WITHDRAWAL STRUCTURE
FULL-HEIGHT SHUTTERS
APPRAISAL STUDY - MARCH 2003

Assumed Water Surface during construction: El. 1290

WOID: GCP17

PROJECT: Columbia Basin - Washington

REGION: Pacific Northwest

FILE:

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	22	Furnish and install Pressure Relief Gates: (9 required)	D8410				
		Gate steel (A36, A572/50) (210,000 lbs/ea.)		1,890,000	LBS	$5.80	$10,962,000.00
		Gate Hoists (Incl. Sheaves, wire rope) (110,000 lbs/ea)		990,000	LBS	$7.00	$6,930,000.00
	23	Furnish and install Low Level Gates: (3 required)	D8410				
		Gate steel (A36, A572/50) (117,300 lbs ea.)		351,900	LBS	$5.80	$2,041,020.00
		Gate Hoists (Incl. Sheaves, wire rope) (65,000 lbs/ea)		195,000	LBS	$7.00	$1,365,000.00
	24	Furnish and install cathodic protection system	D8180	9	EA	$70,000.00	$630,000.00
		(1 system per unit)					
	25	Furnish, install, and test all electrical equipment	D8440	1	LS	$300,000.00	$300,000.00
	26	Furnish, install , and test temperature monitoring equipment	D8410	1	LS	$300,000.00	$300,000.00
	27	Perform gate travel tests (6SS w/3, 3SS w/4)	D8410	30	EA	$7,000.00	$210,000.00
		Subtotal this Sheet					$22,738,020.00
		Subtotal					**$165,037,920.00**
		Unlisted Items (20%)					**$34,962,080.00**
		Contract Cost					**$200,000,000.00**
		Contingencies (25%)					**$50,000,000.00**
		Field Cost					**$250,000,000.00**

QUANTITIES		**PRICES**	
BY Dick LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170

ESTIMATE WORKSHEET

SHEET 1 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
GRAND COULEE P/G PLANT TO BANK'S LAKE
FULL-HEIGHT SELECTIVE WITHDRAWAL SHUTTERS
APPRAISAL STUDY - MARCH 2003
Assumed Water Surface during construction: El. 1290
WOID: GCP17

PROJECT: Columbia Basin - Washington

REGION: Pacific Northwest

FILE: Coulee_TCD_BanksPP.xls

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
		Quantities are for:					
		Full height shutter structures enclosing 11 of 12 intakes (P1-P6 and PG7-PG11)					
		with two gates in each shutter to control withdrawal level.					
		Q/PGunit= 1,700 cfs, Q/Punit= 1,600 cfs. High topography precludes shutter on PG12.					
		Float and sink 6 shutters around P1, P3, P5, PG7, PG9, PG11. Fill in between shutters.					
		Quantities extrapolated from Shasta TCD Final Estimate completed in 1994.					
		Limited calculations were made to adjust quantities.					
	1	Mobilization		1	LS	$5,100,000.00	$5,100,000.00
	2	Mobilization (underwater work)					
	3	Concrete removals:	D8120				
		In dry (at 24 locations on U/S and D/S face)		120	CY	$1,000.00	$120,000.00
		Between 0 and 100 feet (at 12 locations on U/S face)		60	CY	$1,800.00	$108,000.00
	4	Furnish and place reinforced concrete	D8120	40	CY	$900.00	$36,000.00
		in dry, f'c= 4000 psi (incl. Cement)					
	5	Furnish and place concrete reinforcement (150#/CY)	D8120	6,000	LBS	$1.00	$6,000.00
	6	Pressure grout dam connection plates: (2 CF/Plate)	D8120				
		In Dry (2 plates /DC1)		24	EA	$5,000.00	$120,000.00
		Between 0 and 100 feet		36	EA	$10,000.00	$360,000.00
		Between 101 and 200 feet		12	EA	$22,000.00	$264,000.00
	7	Setups per dam connection:	D8120				
		In Dry		24	EA	$930.00	$22,320.00
		Between 0 and 100 feet		72	EA	$2,200.00	$158,400.00
		Between 101 and 200 feet		24	EA	$3,800.00	$91,200.00
		Assumed two setups per dam connection:					
		Setup 1. Attach dam connection steel to dam.					
		Setup 2. Attach shutters and rigid frames to dam connections.					
		(DC plate grouting covered in Item 6, anchors covered in Items 8, and 9)					
		Subtotal this Sheet					$6,385,920.00

QUANTITIES		PRICES	
BY D. LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170 | **ESTIMATE WORKSHEET** | SHEET 2 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
GRAND COULEE P/G PLANT TO BANK'S LAKE
FULL-HEIGHT SELECTIVE WITHDRAWAL SHUTTERS
APPRAISAL STUDY - MARCH 2003

Assumed Water Surface during construction: El. 1290

WOID: GCP17

PROJECT: Columbia Basin - Washington

REGION: Pacific Northwest

FILE:

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	8	Furnish and install 20 mm dia. SS expansion anchors,	D8120				
		6-inch embed (Hilti HSLG-R M 20/30)					
		Between 0 and 100 feet		48	EA	$750.00	$36,000.00
		Between 101 and 200 feet		24	EA	$1,300.00	$31,200.00
	9	Furnish and install 1 3/8-inch diameter Williams	D8120				
		Hollowcore (R1HG) anchors (epoxy coated):					
		In Dry (Embed 3 feet)		48	EA	$4,400.00	$211,200.00
		Between 0 and 100 feet (Embed 3 feet)		144	EA	$2,300.00	$331,200.00
		Between 101 and 200 feet (Embed 3 feet)		48	EA	$4,100.00	$196,800.00
	10	Furnish and install 2 1/2-inch dia. post-tension bars,	D8120	48	EA	$6,000.00	$288,000.00
		in dry, length/bar=30 feet, 6-inch dia hole,					
		(Williams 150 ksi All-thread bar)					
	11	Furnish and install dam connection steel:	D8120				
		Plates, rods, built-up members (A572/50, coated)		250,000	LBS	$3.50	$875,000.00
		Forgings (A668F, galv)-Pins, shackles, turnbuckles		24,000	LBS	$10.00	$240,000.00
	12	Furnish and erect shutter structural steel:	D8120				
		Shapes, plates, built-up members (A572/50, coated)		3,900,000	LBS	$3.50	$13,650,000.00
		5-inch dia. threaded rods, (A572/50, coated),		160,000	LBS	$9.00	$1,440,000.00
		L/rod=50 feet, Number req'd= 48					
		(Float and sink operation similar to Flaming Gorge TCD.)					
		Subtotal this Sheet					$17,299,400.00

QUANTITIES		PRICES	
BY: Dick LaFond	CHECKED	BY: D.L. Maag	CHECKED
DATE PREPARED: 6/17/03	APPROVED	DATE: 17-Jun-03	PRICE LEVEL: Appraisal

CODE: D-8170 **ESTIMATE WORKSHEET** SHEET 3 OF 4

FEATURE: 17-Jun-03 *GRAND COULEE TEMPERATURE MANAGEMENT STUDY* *GRAND COULEE P/G PLANT TO BANK'S LAKE* *FULL-HEIGHT SELECTIVE WITHDRAWAL SHUTTERS* *APPRAISAL STUDY - MARCH 2003* *Assumed Water Surface during construction: El. 1290* **WOID: GCP17**	**PROJECT:** Columbia Basin - Washington **REGION:** Pacific Northwest **FILE:**

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	13	Furnish and install cladding panels:	D8120				
		Structural Steel (A572/50, coated):		992,000	LBS	$3.50	$3,472,000.00
		Steel bridge plank (6x2 - 10 gage - 8.0 lb/sf)		31,000	SF	$15.00	$465,000.00
		(Lowered into shutter slots from top of dam.)					
	14	Furnish and install steel bridge plank on shutter	D8120				
		structures in dry before sinking:					
		Steel bridge plank (9x3 - 3 gage - 15.3 lb/sf)		23,500	SF	$85.00	$1,997,500.00
	15	Miscellaneous Metalwork	D8120	200,000	LBS	$5.20	$1,040,000.00
	16	Furnish and install 5-foot high chain link fence	D8120	500	LF	$30.00	$15,000.00
	17	F&I 1/4" SS gate guide plates	D8120	45,000	LBS	$12.00	$540,000.00
	18	Furnish and install new trashracks (A36, coated)	D8410	1,728,400	LBS	$2.60	$4,493,840.00
	19	Furnish and install Upper Gates: (11 required)	D8410				
		Gate steel (A36, A572/50) (84,500 lbs ea.)		929,500	LBS	$5.80	$5,391,100.00
		Gate Hoists (Incl. Sheaves, wire rope) (45,000 lbs/ea)		495,000	LBS	$7.00	$3,465,000.00
		Subtotal this Sheet					$20,879,440.00

QUANTITIES		PRICES	
BY Dick LaFond	CHECKED	BY D.L. Maag	CHECKED
DATE PREPARED 6/17/03	APPROVED	DATE 17-Jun-03	PRICE LEVEL Appraisal

CODE: D-8170 **ESTIMATE WORKSHEET** SHEET 4 OF 4

FEATURE: 17-Jun-03

GRAND COULEE TEMPERATURE MANAGEMENT STUDY
GRAND COULEE P/G PLANT TO BANK'S LAKE
FULL-HEIGHT SELECTIVE WITHDRAWAL SHUTTERS
APPRAISAL STUDY - MARCH 2003
Assumed Water Surface during construction: El. 1290

WOID: GCP17

PROJECT: Columbia Basin - Washington

REGION: Pacific Northwest

FILE:

PLANT ACCT.	PAY ITEM	DESCRIPTION	CODE	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	20	Furnish and install Pressure Relief Gates: (11 required)	D8410				
		Gate steel (A36, A572/50) (100,000 lbs/ea.)		1,100,000	LBS	$5.80	$6,380,000.00
		Gate Hoists (Incl. Sheaves, wire rope) (52,500 lbs/ea)		577,500	LBS	$7.00	$4,042,500.00
	21	Furnish and install cathodic protection system	D8180	6	EA	$70,000.00	$420,000.00
		(1 system per unit)					
	22	Furnish, install, and test all electrical equipment	D8440	1	LS	$250,000.00	$250,000.00
	23	Furnish, install , and test temperature monitoring equipment	D8410	1	LS	$250,000.00	$250,000.00
	24	Perform gate travel tests (2 per shutter)	D8410	22	EA	$7,000.00	$154,000.00
		Subtotal this Sheet					$11,496,500.00
		Subtotal					**$56,061,260.00**
		Unlisted Items (20%)					**$10,938,740.00**
		Contract Cost					**$67,000,000.00**
		Contingencies (25%)					**$17,000,000.00**
		Field Cost					**$84,000,000.00**

QUANTITIES		PRICES	
BY: Dick LaFond	CHECKED	BY: D.L. Maag	CHECKED
DATE PREPARED: 6/17/03	APPROVED	DATE: 17-Jun-03	PRICE LEVEL: Appraisal